

## APPENDIX A

### UPDATES AND REVISIONS TO THE MRBCA TECHNICAL GUIDANCE

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The department seeks to maintain a viable, relevant, and effective Missouri Risk-Based Corrective Action (MRBCA) process with the flexibility necessary to meet changing environmental conditions and regulations. In addition, we expect that department staff and users of this guidance will identify areas of needed improvement over time. This appendix provides a framework for updating this guidance. Changes in the guidance will also be reflected in changes to the associated risk-based rules to the extent necessary to implement changes in the guidance. We envision ~~two~~three kinds of updates.

The first type of update addresses errors, omissions, clarifications or corrections to this guidance that do not involve substantive issues. These kinds of changes will be made as determined to be necessary by the Department of Natural Resources and as quickly as possible. We anticipate these changes to be handled by means of an “Errata Notice” that can be inserted into the document and that will be posted on the MRBCA web site maintained by the department.

The second type of update would be more substantive technical or policy issues that interpret or build upon the current technical guidance. Substantive changes to the guidance could also be made in this manner as long as they did not conflict with existing laws and regulations. These Technical and Policy Memoranda will also be posted on the MRBCA web site.

The ~~second~~third type of update will encompass a complete review that responds to changes in scientific knowledge, improved methodologies, and new and better information. Every three years, the department will initiate this systematic review and evaluation of this guidance. The first complete review and evaluation will begin three years from the date of final publication of this guidance. It should be staggered with any review of the risk-based corrective action guidance that covers the petroleum storage tanks so that the reviews are not on going in the same time period. Any changes made in the guidance will need to be conducted in step with any required regulatory procedures.

The review will be done through a public participation process and in concert with a stakeholder group that, at a minimum, is comprised of relevant federal, state and local agencies, regulated entities and their representatives, and interested citizens. The review process will identify and plan for areas of responsibility, a timeline for completion, quality control procedures, and a publication mechanism.

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## APPENDIX B

### DEFAULT TARGET LEVELS AND TIER 1 RISK-BASED TARGET LEVELS

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\* Values associated with chemicals that are common to both the departmental and tanks MRBCA (such as benzene) are being posted separately. However, when final, this information will be included in this guidance.

\*\* Horizontal migration distance in the saturated zone is equal to zero.

Note that the chemicals in MRBCA Process for Petroleum Storage Tanks are highlighted.

**APPENDIX C**  
**ESTIMATION OF REPRESENTATIVE**  
**SOIL AND GROUNDWATER CONCENTRATIONS**

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## C.1 BACKGROUND

When performing a risk assessment, it is assumed that a receptor would typically be exposed to chemicals of concern (COCs) over a defined geographical area, for a specified exposure duration, and through one or more routes of exposure. The geographical area and the exposure duration for a receptor may vary for different routes of exposure. The geographical area over which a receptor is exposed to COCs is called the exposure domain. Because COC concentrations typically vary over the exposure domain and exposure duration, it is necessary to estimate a representative COC concentration consistent with the receptor's exposure domain and exposure duration.

A representative COC concentration is the average concentration to which the receptor is exposed over the specified exposure duration, within a specified geographical area, and for a specific route of exposure. In most risk assessments, the exposure point concentration is assumed constant over the exposure duration.

Representative concentrations are necessary for both the “backward” and “forward” mode of risk assessments. The backward mode of risk assessment results in target levels for each complete route of exposure identified in the exposure model and each COC. Representative concentrations are used in the risk management step in which the target concentrations are compared with the representative concentrations. The forward mode of risk assessment results in the calculation of risk for each complete route of exposure identified in the exposure model, and representative concentrations are used to estimate the risk.

The calculation of representative concentrations is complicated by several factors. These include:

- Spatial variability in the concentrations,
- Temporal variability in the concentrations, and
- Lack of sufficient site-specific concentration data.

Further complication arises because environmental data is typically obtained through biased sampling in that the sampling is focused on identifying the source areas and does not consist of samples collected randomly over the exposure domain. Additional complications arise because the concept of representative concentration is often associated with a site as opposed to an exposure pathway and receptor. Because there may be several complete pathways at a site, several representative concentrations, one for each complete pathway, must be estimated for each receptor. This appendix discusses the methodology used to estimate the representative concentrations for each complete route of exposure.

The calculation of the representative concentration requires the following steps for each receptor:

1. Identification of all of the media of concern. Typically these include surficial soil, subsurface soil, soil up to the depth of construction, and groundwater,
2. Identification of all the complete routes of exposure under current and future



- conditions,
3. Identification of the exposure domain for each media identified in Step 1, and each complete route of exposure identified in Step 2,
  4. Identification of the COC concentration data available within the exposure domain for each media, and
  5. Calculation the representative concentration, which would be the average of the data from Step 4 above.

When using the average concentration as the representative concentration, the value should not be artificially lowered or “diluted.” To avoid this, the following should be kept in mind ([also refer to Section 9.5, “Recommend the Next Course of Action”](#)):

1. Do not use data beyond the exposure domain unless there is not enough data within the domain and data is available just outside the domain. If data is available just outside the exposure domain, judgement should be used whether to interpolate and use this data or to collect additional data within the exposure domain.
2. Within the exposure domain, replace the non-detect values with half the detection limit. Concentrations with a J laboratory qualifier, which is a judgement made at the laboratory, should use the laboratory-estimated value.
3. As a simple or red flag check, determine if the maximum concentration of any COC exceeds ten times the representative concentration of that COC for any exposure pathway. Note the maximum concentration here refers to the maximum concentration in the exposure domain, not the site-wide maximum concentration. Possible reasons for an exceedance could be:
  - The maximum concentration is an outlier,
  - The average concentration was inaccurately calculated,
  - The site is not adequately characterized, or
  - A hot spot may not have been adequately characterized.
4. If the representative concentration is based on extrapolation using a model, the model must be supported by site-specific data.
5. When calculating the representative groundwater concentration, first estimate the average concentration in each well based on recent data, assuming data from multiple events is available, and then use the average of each well to estimate the representative concentration.
6. If free product is present at a monitoring point, use the effective solubility or effective vapor pressure to estimate the concentration at that point.
7. For wells with multiple years of groundwater data, use the most recent two years of data to estimate the representative concentration. In certain cases, data that is more than two years old may be used, but it must be justified (also refer to C.2.4.1).
8. If the area of impact is smaller than the exposure domain, the exposure factors may be modified (in Tier 3 evaluation) and representative concentrations calculated over the area of impact.
9. For the subsurface-soil-to-indoor-inhalation pathway, do not use soil data collected below the water table. Similarly, for the groundwater-to-indoor-inhalation pathway, groundwater data from the first encountered saturated zone must be used.

## **C.2 CALCULATION OF REPRESENTATIVE CONCENTRATIONS**

### **C.2.1 Surficial Soil (0-3 feet below ground surface)**

The Missouri Risk-Based Corrective Action (MRBCA) process requires the evaluation of four routes of exposure associated with surficial soil:

1. The ingestion of COCs in groundwater due to leaching of residual COCs present in the surficial soil,
2. Accidental ingestion of soil,
3. Outdoor inhalation of vapors and particulates from surficial soil emissions, and
4. Dermal contact with surficial soil.

The latter three pathways are combined and referred to as the “direct contact with soil” pathway. Thus at least two different surficial soil representative concentrations are required, one for leaching to groundwater and one for direct contact with soil. In certain cases, depending on use and characteristics of the site (factors that determine the exposure domain), a single representative concentration may suffice for both pathways.

#### **C.2.1.1 Representative Surficial Soil Concentration for Leaching to Groundwater**

The exposure domain for this pathway is the area of release through which leachate generation may occur and COCs can migrate to the water table. The representative surficial soil concentration should be calculated using the surficial soil data collected within this exposure domain. Thus, prior to calculating the representative concentration, it is necessary to clearly define the horizontal dimensions of the release area and to identify the surficial soil data available within the release area.

#### **C.2.1.2 Representative Concentrations for Direct Contact Pathway**

The representative surficial soil concentration (0 to 3 feet), has to be based on the receptor’s exposure domain, - that is, the area of the site over which the receptor might be exposed to the surficial soil. The exact domain of the receptor is difficult to estimate especially because the domain must be representative of a period of time equal to the receptor’s exposure duration. In the absence of specific information about the receptor’s activities, the unpaved portion of a site may be considered the receptor’s domain. For potential future exposures and in the absence of any engineering controls, it may be necessary to assume that the pavement will be removed and the receptor will be exposed to surficial soil.

To calculate the representative concentration for the direct contact pathway, one must (i) estimate the receptor’s domain(s), and (ii) determine the number of soil samples available within this domain or the number of samples necessary to represent the domain.

For a non-resident worker, the average concentration over the domain may be used. For a child receptor, the maximum concentration must be used and, therefore, a representative concentration need not be calculated if a child is an actual or potential

receptor. For direct soil contact pathway for a construction worker, refer to Section C.2.3.

## **C.2.2 Subsurface Soil (greater than 3 feet below ground surface)**

The MRBCA process includes the following two routes of exposure associated with subsurface soil: (i) leaching of residual COC concentrations in the subsurface soil to groundwater, and (ii) indoor inhalation of vapor emissions. Thus, a representative concentration must be calculated for each complete pathway. Additional representative concentrations are required if the receptor's domain differs under current and future conditions.

### **C.2.2.1 Representative Subsurface Soil Concentration for Protection of Groundwater**

The representative concentration for this pathway should be the average concentration in subsurface soil measured within the area of impact.

### **C.2.2.2 Representative Subsurface Soil Concentration for Protection of Indoor Inhalation**

Subsurface soil concentrations protective of indoor inhalation are estimated using an emission model such as the Johnson and Ettinger (2001) model. This model assumes that chemicals volatilize from the subsurface soil source, travel vertically upwards without any lateral or transverse spreading, and enter the building through cracks in the foundation and floor. To ensure consistency with the model, the representative concentration for this pathway should be based on soil concentrations measured directly below the footprint of the enclosed space.

To evaluate the potential future indoor inhalation pathway, (i.e., an enclosed structure is constructed over contaminated soil), the size (footprint) and location of the planned structure must be estimated. In the absence of site-specific information regarding planned structures, the future location and size of the structure must be approximated based on the evaluator's professional judgement. A conservative option is to locate the hypothetical structure over the area of release (that is, the area of maximum COC concentrations). However, this is only one conservative option and its applicability will vary from site to site. For sites where the footprint of a current on-site structure is or might be different from that of a structure erected in the future, a representative subsurface soil concentration must be calculated for both the current and potential future structure.

To estimate the representative concentration, the evaluator must:

1. Identify the footprint of the structure within which the receptor is located,
2. Identify the footprint of the potential future enclosed structure,
3. Identify the soil concentration data available within each of these two footprints, and
4. Calculate the average of these concentrations.

If sufficient data are not available within the footprint, data collected within 20 feet of the footprint may be used. Data beyond 20 feet may also be considered in cases where preferential pathways such as macropores, utility conduits, or fractures may cause vapor migration towards the buildings. Generally, vapor concentrations decrease with increasing distances from the source. If it can be justified, and when calculating the representative concentrations, a horizontal attenuation factor may be applied to concentrations beyond 20 feet.

If several samples within and adjacent to the footprint are available, more weight may be given to the samples collected within and close to the footprint. Two scenarios are possible: (i) the building footprint is located entirely within the contaminated area, and (ii) the building footprint is partially located within the contaminated area. For both scenarios, the representative soil concentration would typically be based on data collected within and about 20 to 100 feet or more from the footprint of the building. In the second scenario, the representative concentration is effectively reduced because a portion of the structure lies over uncontaminated soil.

### **C.2.3 Representative Concentration for Construction Worker**

The MRBCA process requires the evaluation of the following three routes of exposure for the construction worker:

1. Accidental ingestion, dermal contact and outdoor inhalation of vapors and particulates from soil,
2. Outdoor inhalation of vapors from groundwater, and
3. Dermal contact with groundwater.

Thus three representative concentrations are required. Each of these is discussed below.

#### **C.2.3.1 Representative Soil Concentration**

For the construction worker, no distinction is made between surficial and subsurface soil because, during construction, the construction worker might be exposed to both. To estimate the representative concentration for the construction worker, it is necessary to identify the (i) depth of construction, (ii) areal extent of construction, and (iii) the number of samples within the zone of construction. The potential future depth of construction should be estimated based on the likely type of structure that might be built and by identifying the typical depth of utilities on and adjacent to the site. If the areal extent of the construction area is not known, a conservative option (not the only option), would be to assume that the zone will be within the area of release. The representative concentration would be the averaged concentration within this zone of construction.

#### **C.2.3.2 Representative Groundwater Concentration**

As with estimating representative soil concentrations, it is necessary to estimate the areal extent of the construction zone and identify the groundwater data available for this zone.

The representative concentration would then be calculated as the average concentration within this zone. Temporal variations in groundwater concentrations should be evaluated as discussed in Section B.2.4.1.

## **C.2.4 Groundwater**

The MRBCA process requires the evaluation of the following three routes of exposure associated with groundwater:

1. Ingestion of groundwater,
2. Dermal contact with groundwater, and
3. Indoor inhalation of vapor emissions from groundwater (only from shallow groundwater).

Where multiple aquifers are present, the shallowest aquifer would be considered for the volatilization pathway. The specific aquifers that are or might be used for domestic use or in another manner in which dermal contact could occur must be considered for the ingestion and dermal contact pathways. Representative concentrations must be calculated for each aquifer that is or is reasonably likely to be used for domestic purposes. Thus, depending on the number of complete pathways, up to three different groundwater representative concentrations, one for each complete pathway, must be calculated.

### **C.2.4.1 Representative Demonstration Well Concentration for Protection of Groundwater Ingestion (Drinking Water Pathway)**

For the ingestion of groundwater pathway, maximum contaminant levels (MCLs) or, where MCLs are lacking, calculated risk-based concentrations, must be met at the point of exposure (POE) well. Often the point of exposure well is hypothetical and, therefore, data for the POE might not be available. In either case, one or more point of demonstration (POD) wells must be identified and target concentrations must be calculated for these wells.

The representative concentration at the POD or POE should be calculated based on measured COC concentrations, as discussed below:

- If COC concentrations in groundwater are stable, the representative concentration is the arithmetic average of the most recent data collected over a period of at least two years on at least a quarterly basis.
- If COC concentrations are decreasing, the representative concentration is the arithmetic average of the most recent data collected over a period of at least one and one-half years on at least a quarterly basis.

#### **C.2.4.2 Representative Groundwater Concentration for Protection of Indoor Inhalation**

Groundwater concentrations protective of indoor inhalation are typically estimated using a model such as the Johnson and Ettinger (2001) model. This model assumes no lateral or transverse spreading of the vapors as they migrate upward from the water table through the capillary fringe and the vadose zone and into the enclosed space. Thus, representative concentrations for this pathway should be based on groundwater concentrations measured within the footprint of the building or up to 20 feet from the building. As mentioned above, in a few cases data from a larger area may be used. Refer to Section C.2.2.2 for a discussion of the evaluation of future structures and their relationship to the contaminated area.

For the groundwater to indoor air pathway, multiple representative concentrations might be needed if the plume has migrated below several current or potential future buildings. For example, if a plume has migrated or is likely to migrate below two different buildings, one on-site and one off-site, a representative concentration would have to be calculated for each building.

After identifying the location of the building footprints (whether real or hypothetical) and the available groundwater monitoring data within or adjacent (within 20 feet and in some cases up to or more than 100 feet) to each footprint, the average concentration within each footprint must be estimated, as discussed in Section C.2.2.2. However, groundwater data may not be available for each footprint; therefore, several options are available. These include:

1. Installation of additional monitoring wells within the footprint lacking data,
2. Interpolation or extrapolation of existing data (in the case where the plume originates under a building, extrapolated data gathered from areas adjacent to the footprint may not be adequate) or,
3. As a conservative approach, use of data from wells located upgradient of the building that is, between the building and the source

#### **C.2.4.3 Representative Groundwater Concentration for Dermal Contact**

The average concentration of COCs in the groundwater that a receptor might come in contact with is used as the representative concentration. Note that temporal variations in COC concentrations will be considered as discussed in Section C.3. More than one representative concentration might be needed where a receptor might contact groundwater from more than one aquifer or saturated zone.

### **C.3 GENERAL CONSIDERATIONS FOR CALCULATING REPRESENTATIVE CONCENTRATIONS**

As discussed in this document, calculation of representative concentrations requires considerable professional judgement. Prior to performing the computations identified in Section C.2, the following should be considered:

- Evaluate whether the spatial resolution of the data is sufficient. While an exact number of samples cannot be specified herein due to the variability in conditions from site to site, data should be available from known or likely release areas and the various receptors' exposure domains.
- ~~If the data are "old" (greater than four years old) and the COC concentrations exceed the Tier 1 risk-based target levels, or if a new spill has been documented or is suspected, new data should be collected. If sufficient new data are collected, the new data may be used for risk evaluation and the old data disregarded. A new release will always require the collection of additional data.~~
- If the data are old (greater than four years old) and the COC concentrations exceed Tier 1 Risk Based Target Levels, new data may be collected (especially groundwater data). If a new release has been documented, new data must be collected in order to characterize accurately the nature and extent of the current impact. If old data are to be eliminated from the risk evaluation, the reason for its elimination must be clearly documented in the Tiered Risk Assessment Report (see section 7.2 of the MRBCA guidance).
- Non-detect soil samples located at the periphery of the exposure domain of interest should not be used.
- Non-detect results associated with certain COCs within the exposure domain should be replaced by half the detection limit.
- If multiple surficial soil samples and/or multiple subsurface soil samples are available from the same borehole within the exposure domain, the average concentration of these samples may be used.
- The maximum concentration of any COC within the exposure domain should not exceed ten times the representative concentration. If this situation occurs, further evaluation of the analytical data to assess its usability may be necessary.
- In certain cases, an area-weighted average may be a better estimate of the representative concentration. If a gridded sampling pattern has been used to sample soil, the arithmetic average is a good approximation of the area-weighted average. However, if a biased sampling pattern has been used, then it may be necessary to use an area-weighted average to accurately determine the representative concentration. Prior to performing the area-weighted average, the remediating party should discuss the specifics with the project manager.

The following considerations are necessary to evaluate representative groundwater concentrations.

- To account for temporal variations in groundwater concentrations, the representative concentration in a well may be estimated as:
  1. If COC concentrations in groundwater are stable, the arithmetic average of the most recent data collected over a period of at least two years on at least a quarterly basis.
  2. If COC concentrations are decreasing, the arithmetic average of the most recent data collected over a period of at least one and one-half years on at least a quarterly basis.

Data from wells on the periphery of the exposure domain having COC concentrations consistently below detection limits cannot be used to calculate representative concentrations.

- For wells that contain or have contained free product within the most recent two years, the concentration representative of the well should be the effective solubility of the various chemicals representing the free product in the well.



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**Table C-1**  
**Calculation of Representative Concentrations**

Route of Exposure	Calculation of Representative Concentration
<b>Surficial Soil (0 to 3 feet bgs)</b>	
Soil concentration protective of leaching to groundwater or surface water body	Average of surface soil concentrations collected within the area of release.
Direct contact with soil including ingestion of soil, dermal contact with soil, and the outdoor inhalation of vapors and particulates emitted by surficial soils	Average of the surface soil concentrations within exposure domain for non-residential receptor. <u>Maximum concentration</u> for child receptor.
<b>Subsurface Soil (greater than 3 feet bgs)</b>	
Indoor inhalation of vapor emissions	Average of the subsurface soil concentrations collected below or within 20** ft of the real or hypothetical footprint of the building (Excluding concentrations below water table and capillary fringe).
Soil concentration protective of leaching to groundwater	Average of the subsurface soil concentration within the area of release (Excluding concentrations below water table and capillary fringe).
<b>Groundwater</b>	
Indoor inhalation of vapor emissions	Average of the groundwater concentrations within 20** feet of the footprint of the real or hypothetical building
Dermal contact with groundwater	Average of the groundwater concentrations that a receptor may come in contact with
Groundwater domestic use pathway	
<ul style="list-style-type: none"> <li>Concentration at POE</li> </ul>	Average of the groundwater concentrations*
<ul style="list-style-type: none"> <li>Concentration at POD</li> </ul>	Average of the groundwater concentrations*

\*: Refer to Section C.2.4.1.

\*\*: Refer to discussion in Section C.2.2.2.

## **APPENDIX D**

### **PROCEDURE FOR REVIEW OF THE RISK-BASED CORRECTIVE ACTION (RBCA) DECISIONS**

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#### ***Introduction***

With the advent of this new RBCA guidance in Missouri, occasions for questions and differences between the department, owners, consultants and others over site-specific decisions will occur. Most questions will likely be resolved at the Project Manager level. This procedure lays out a process for resolving questions that cannot be resolved between the Project Manager and the affected person. To be effective, the review process must be thorough, impartial and timely.

#### ***Who may request a RBCA Review?***

Any person affected by a RBCA decision may request a review.

#### ***What decisions may be reviewed?***

Any written decision of the Project Manager, including those transmitted via e-mail, regarding the applicability of the Missouri RBCA guidance or rules to a specific site being addressed under those rules or guidance. Likely areas of review will be site characterization workplans and reports, site conceptual model/risk assessment reports, corrective action workplans and reports, activity and use limitations and long-term stewardship.

#### ***Evaluation by Unit Chief***

Where the decision in question is made by a Project Manager at the “staff” level, the affected person (Requester) shall contact the Project Manager’s immediate supervisor and request an evaluation of the matter, before initiating a written request for a RBCA Review. The process for this may be any that is mutually agreeable to all parties. For example, a phone conference between the Requester and the Unit Chief, with or without the Project Manager, may serve to resolve the issue. When contacted for an evaluation, the Unit Chief must make every effort to address the matter and render a decision in a timely fashion. The Unit Chief will convey the decision in written form.

#### ***Requesting a RBCA Review***

If the Requester feels that the response from the pre-review is not satisfactory or timely, or if the decision in question is made by a Project Manager at the “Unit Chief” level, the Requester may initiate a RBCA Review by submitting the relevant information on the attached form “Request for RBCA Review” or through some other means that provides the same information. The request shall include a written summary of the matter and include supporting documentation as needed, or refer to such documentation that may be in the department’s files. When using supporting documentation the Requester shall

point to the specific pages, sections or items that are relevant. The request must be submitted in writing or via email.

The request shall go first to the Section Chief of the Project Manager who rendered the decision in question. The Section Chief may either attempt to resolve the matter through the RBCA Review Process or may refer the matter immediately to the Program Director. The Section Chief may solicit the review and input of other section chiefs. If referring immediately to the program director, the Section Chief shall do so within three working days of receipt.

If the Requester does not agree with the findings of the Section Chief, the Requester may ask in writing or by email that the Program Director review the matter.

### ***The RBCA Review Process***

The Reviewer (Section Chief or Program Director) shall review the file and impartially consider the relevant facts. The Reviewer shall discuss the substance of the Request for Review with the Requester at a mutually acceptable time and manner. The Requester may bring technical consultants and the Reviewer may include the Project Manager and other technical staff. Attorneys or other legal staff shall not participate, either for the Requester or the department, except by mutual agreement of all parties. The reviewer shall carefully and without partiality to department staff consider the facts and viewpoints of both sides and make every effort to take into account the meaning and intent of the written RBCA guidance.

The Reviewer shall provide a written decision summarizing the issue under review, the relevant facts of the decision, the rationale behind the decision and any information or considerations outside of the specific situation that were used in making the decision.

The Requester shall not unreasonably expand the original scope of the request except by mutual agreement, until the program has issued a final decision on the original request.

The decision of the Program Director shall be a final decision and may be appealed. Decisions made within the Hazardous Waste Program would be appealed to the Hazardous Waste Management Commission under 640.010 RSMo. This appeal is a contested case.

Any written decision shall be retained in the Hazardous Waste Program (HWP) file for the site as a public record under the Sunshine Law. The HWP shall maintain a compendium of review decisions made under this process. The compendium shall be updated regularly and posted to the department's web site, and shall serve as a reference document when the RBCA guidance and rules are updated.

### ***Timeframes***

A Requester must file a Request for RBCA Review within ninety (90) days of the

original decision except in the case of a “clean letter” or “no further remedial action letter,” in which case the Requester must file the request within thirty (30) days. The Section Chief will respond with a final decision within forty-five (45) days of receipt of the request.

If the Requester disagrees with the Section Chief’s decision, he or she may request a review by the Program Director within sixty (60) days of the Section Chief’s decision.

The Program Director as Executive Director will respond with a final decision within forty-five (45) days of receipt of the request.

These timeframes may be extended by mutual agreement of all parties.

## Request for Review of RBCA Decision

R e q u e s t e r  I n f o	Requester Contact Info _____	Date of Request _____
	Address _____	
	Telephone Number _____	
	Name of Site _____	Date Received by HWP _____
	Address of Site _____	
S e c t i o n  C h i e f	Summary of Issue( To be Completed by the Requester; Use extra pages, attachments as necessary)	
	I hearby request a RBCA review of this matter by the Hazardous Waste Program	
	Requester Signature _____	Date _____
P r o g r a m  D i r e c t o r	Section Chief: Summary of Findings and Comments (Use additional pages as necessary)	
	S.C. Signature _____ Date _____	
	Program Director: Findings and Comments (Use additional pages as necessary)	
	P.D. Signature _____	Date _____

## APPENDIX E

### DEVELOPMENT OF RISK-BASED TARGET LEVELS

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## E.1 INTRODUCTION

Appendix E provides the inputs required to calculate default target levels (DTLs) and Tier 1 risk-based target levels. Several of these parameters, as explained in Section 9.0, may also be used in Tier 2 evaluation. Specifically the calculation of the Tier 1 risk-based target levels and the Tier 2 and 3 site-specific target levels requires the following:

- Acceptable risk level,
- Chemical-specific toxicological factors,
- Physical and chemical properties of the chemicals of concern (COCs),
- Receptor-specific exposure factors,
- Fate and transport parameters, and
- Mathematical models.

Each of these factors is discussed below. In addition, this appendix discusses the target levels for lead (Section E.10) and the estimation of risk and target levels when light or dense non-aqueous phase liquid (LNAPL/DNAPL) is present on/in the groundwater (Section E.11).

For Tier 1 risk assessments, generic Tier 1 risk-based target levels have been calculated by the department for each of the COCs, the receptors (child, adult resident, age-adjusted resident, non-residential worker, and construction worker), and the following exposure pathways using conservative assumptions applicable to most Missouri sites.

### Pathways for Surficial Soils, defined as 0 to 3 feet below ground surface (bgs)

- Leaching to groundwater and potential use of groundwater,
- Leaching to groundwater and subsequent migration to a surface water body, and
- Ingestion of soil, dermal contact with soil, and outdoor inhalation of vapors and particulates emitted by surficial soils.

### Pathways for Subsurface Soils, defined as greater than 3 feet bgs to the water table

- Volatilization and upward migration of vapors from subsurface soil and potential indoor inhalation of these vapor emissions,
- Leaching to groundwater and potential use of groundwater, and
- Leaching to groundwater and subsequent migration to a surface water body.

### Pathways for Groundwater

- Volatilization and upward migration of vapors from groundwater and potential indoor inhalation of these vapor emissions,
- Volatilization and upward migration of vapors from groundwater and potential outdoor inhalation of these vapor emissions,
- Ingestion of water if the domestic use of groundwater pathway is complete,
- Dermal contact with groundwater, and



- Migration to a surface water body and potential impacts to surface waters.

The following pathways for surface water and sediments are not included in Tier 1 calculations:

- Ingestion of surface water,
- Contact with surface water during recreational activities (ingestion, inhalation of vapors, and dermal contact),
- Ingestion of fish, and
- Contact with (accidental ingestion and dermal contact with) sediments.

### Other Pathways

In a Tier 2 assessment, leaching to groundwater, horizontal migration of the plume under a building, and volatilization from the plume into the building are other surface and subsurface pathways that may be complete at some sites.

At some sites, other routes of exposure may be significant. These include exposure due to (i) ingestion of produce grown in impacted soils, (ii) exposures associated with use of groundwater for irrigation purposes, (iii) use of groundwater for industrial purposes, or (iv) ingestion of fish or other aquatic organisms that have bioaccumulated COCs through the food chain as a result of surface water or sediment contamination. At sites where these pathways are complete, they must be evaluated under Tier 3 risk assessment.

The resultant generic Tier 1 risk-based target levels are presented in Appendix B. The term generic implies that the risk-based target levels have not been adjusted for the presence of other routes of exposure and COCs, i.e. additive and cumulative risk.

For Tier 2 risk assessments, the remediating part must calculate the site-specific target levels using technically justifiable, site-specific data. The default fate and transport models used for developing the generic Tier 1 risk-based target levels must be used. For Tier 3 assessments site-specific target levels would be calculated using site-specific data and possibly alternative fate and transport models, if approved by the department. Also refer to Table 2-1.

## **E.2 ACCEPTABLE RISK LEVEL**

A risk-based decision making process requires the specification of an acceptable risk level for both carcinogenic and non-carcinogenic adverse health effects. For carcinogenic effects, risk is quantified using individual excess lifetime cancer risk (IELCR) and for non-carcinogenic effects, the risk is quantified using a hazard quotient (HQ) or hazard index (HI) which is the sum of hazard quotients when multiple chemicals and multiple exposure pathways are evaluated.

For evaluating the domestic use of water, maximum contaminant levels (MCLs) are used as the target concentrations at the point of exposure. For COCs that do not have MCLs,

the target concentration at the point of exposure (POE) was estimated assuming ingestion of groundwater and indoor inhalation of vapors due to water use under residential conditions.

Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected as per 10 CSR 20-7.031. Allowable concentrations in surface water depend on the streams' designated beneficial use.

The generic Tier 1 risk-based target levels are based on acceptable risk levels of  $1 \times 10^{-5}$  for the carcinogenic chemicals and a hazard quotient of 1.0 for non-carcinogenic chemicals. The calculation of generic risk-based target levels does not account for cumulative site-wide risk. As explained in Section 8.6, these generic target levels may need to be adjusted to account for the cumulative site-wide risk. The acceptable risk levels are as follows:

#### Carcinogenic Risk

- The total risk for each COC, which is the sum of risk for all complete exposure pathways for each COC, must not exceed  $1 \times 10^{-5}$ .
- The cumulative site-wide risk (sum of risk for all COCs and all complete exposure pathways) must not exceed  $1 \times 10^{-4}$ .

#### Non-carcinogenic Risk

- The hazard index for each COC, which is the sum of hazard quotients for all complete exposure pathways for each COC must not exceed 1.0.
- The site-wide hazard index, which is the sum of hazard quotients for all COCs and all complete exposure pathways, must not exceed 1.0.

Note if the hazard index exceeds 1.0, the hazard index corresponding to a specific toxicological end point may be calculated by a qualified toxicologist. In this case, the specific hazard indices for each toxicological end point must be less than unity (1.0).

### **E.3 QUANTITATIVE TOXICITY FACTORS**

Table E-1 gives the toxicity values for the over 300 chemicals (not including the petroleum fractions) considered in the Missouri Risk-Based Corrective Action (MRBCA) process.

Typically, these toxicity values will also be used for Tier 3 risk assessments, although alternate values may be used at Tier 3 with adequate justification and the approval of the department.

The toxicity data was extracted from the hierarchy of sources as per ***“Human Health Toxicity Values in Superfund Risk Assessments,” OSWER directive 9285.7-53, December 5, 2003.*** Specifically it included:

- ~~(i)~~1. Tier 1: Integrated Risk Information System (IRIS),
- ~~(ii)~~2. Tier 2: Provisional Peer Reviewed Toxicity Values (PPRTVs),
- ~~(iii)~~3. Tier 3: Miscellaneous Sources:
  - ~~(i)~~ National Center for Environmental Assessment (NCEA) as listed in USEPA's Region IX Preliminary Remediation Goal (PRG) Table,
  - ~~(ii)~~ California Office of Environmental Health Hazard Assessments (OEHHAs) chemical database, ~~and~~
  - ~~(iii)~~ Health Effects Assessment Summary Tables (HEAST) as listed in USEPA's Region IX ~~Preliminary Remediation Goal (PRG) tables,~~ and (iv) Table for Texas Risk Reduction Program.

Footnotes to Table E-1 indicate the source for each value.

Dermal toxicity values are not available in the above sources; therefore the dermal toxicity values were calculated. The assumption underlying the calculation of dermal toxicity values is that the dermal toxicity of the chemical is the same as the oral toxicity values, except that a semi-permeable barrier (the skin) affects absorption. Using oral toxicity values to calculate dermal toxicity values is based on sound toxicological principles, and in the absence of direct measurement of dermal toxicity, considered an acceptable alternative by the USEPA. However, the calculation is complicated due to the fact that different chemicals pass through the skin with different efficiencies. These differing efficiencies are factored into the formulae for dermal toxicity as the term "oral absorption factors ( $RAF_o$ )."

The formulae for calculation of slope factor ( $SF_d$ ) and reference dose ( $RfD_d$ ) for dermal exposure are as below:

$$SF_d = \frac{SF_o}{RAF_o} \quad (1)$$

$$RfD_d = RfD_o \times RAF_o \quad (2)$$

where,

- $SF_o$  = Slope factor for oral exposure ( $\text{mg/kg-day}$ )<sup>-1</sup>,
- $RfD_o$  = Reference dose for oral exposure ( $\text{mg/kg-day}$ )<sup>-1</sup>, and
- $RAF_o$  = Oral ~~ab~~sorption factor (dimensionless).

The oral absorption factors are not readily available. Conservatively, a value of 1.0 was assigned for all chemicals.

The dermal absorption factors were obtained from the ~~USEPA's~~ ***Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual, Part E Supplemental Guidance for Dermal Risk Assessment*** (~~July~~ USEPA, 2004). However, this guidance does not have any recommendations for volatile organic compounds (VOCs), or inorganic compounds. For these compounds, the absorption factors were obtained from the USEPA Region III and RAGS, Volume 1, Part A.

The parameters used for dermal contact pathway are shown in Table E-2 and are

discussed below:

### **Permeability Coefficient**

For organic chemicals, the chemical-specific permeability coefficients in water were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the permeability constant,  $K_p$  (cm/hr), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$\log K_p = -2.80 + 0.66(\log K_{ow}) - 0.0056MW \quad (3)$$

where,

$$\begin{aligned} K_{ow} &= \text{Octanol-water partition coefficient (dimensionless), and} \\ MW &= \text{Molecular weight (g/mole).} \end{aligned}$$

Note the  $MW$  and  $K_{ow}$  are presented in Table E-3.

For metals and inorganics, the permeability coefficients were obtained from Exhibit B-4 of the *RAGS Volume I, Part E* (USEPA, 2004). If no value is available, the permeability coefficient of  $1 \times 10^{-3}$  cm/hr is recommended as default value (USEPA, 2004).

### **Relative Contribution of Permeability Coefficient**

The relative contribution of permeability coefficients for the chemicals was obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the relative contribution of permeability coefficient,  $B$  (unitless), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$B = K_p \frac{\sqrt{MW}}{2.6} \quad (4)$$

### **Lag Time**

The lag times for the chemicals,  $\tau_{event}$  (hr/event), were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004).

As per the *RAGS Volume I, Part E* (USEPA, 2004), the equation to estimate  $\tau_{event}$  is derived as below:

$$\frac{D_{sc}}{l_{sc}} = 10^{(-2.80 - 0.0056MW)} \quad (5)$$

$$\tau_{event} = \frac{l_{sc}^2}{6 \times D_{sc}} \quad (6)$$

where,

$$\begin{aligned} D_{sc} &= \text{Effective diffusion coefficient for chemical transfer through the stratum corneum (cm}^2\text{/hr), and} \\ l_{sc} &= \text{Apparent thickness of stratum corneum (cm).} \end{aligned}$$

The lag time is dependent on the effective diffusion coefficient for chemical transfer through the stratum corneum and the apparent thickness of stratum corneum. Assuming  $l_{sc} = 10^{-3}$  cm as a default value for the thickness of the stratum corneum,  $\tau_{event}$  becomes:

$$\tau_{event} = 0.105 \times 10^{(0.0056MW)} \quad (7)$$

For chemicals not listed in Exhibit B-3,  $\tau_{event}$  was estimated using Equation (7).

Note that Equation (7) is based on the assumption that all chemicals absorbed into the skin during the exposure event would eventually be absorbed into the systemic circulation, with the stratum corneum being the main barrier for most chemicals. For highly lipophilic chemicals, the viable epidermis can be a significant barrier for chemical transfer from the stratum corneum to the systemic circulation. When this occurs, the relative rate of desquamation of the stratum corneum and cell proliferation rate at the base of the viable epidermis contribute to a net decrease in the total amount of absorbed chemical. For similar reasons, stratum corneum desquamation can reduce the amount of absorption for chemicals that are not highly lipophilic but large enough that penetration through the stratum corneum is slow.

### **Time to Reach Steady-State**

The time to reach steady-state for the chemicals considered were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the time to reach steady-state,  $t^*$  (hr), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

If  $B < 0.6$  or  $B = 0.6$ ,

$$t^* = 2.4\tau_{event} \quad (6)$$

If  $B > 0.6$ ,

$$t^* = 6\tau_{event} \times (b - \sqrt{b^2 - c^2}) \quad (7)$$

where  $b$  and  $c$  are correlation coefficient which have been fitted to the data from Flynn,

G.L. (1990) and are expressed as below:

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)} \text{ and } b = 2 \times \frac{(1 + B)^2}{\pi} - c$$

### Fraction Absorbed Water

The fraction absorbed water for the chemicals considered were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the fraction absorbed water, *FA* (unitless), was estimated from Exhibit A-5 of the *RAGS Volume I, Part E* (USEPA, 2004).

~~The chemical specific dermal permeability coefficient in water for the chemicals considered in the MRBCA were obtained from Exhibit B-2 of the *Risk Assessment Guidance for Superfund (RAGS) Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)*, July 2004. This document provides calculated and experimentally measured values of dermal permeability coefficients for a large number of chemicals. When both values are available for a chemical the document suggests the use of calculated values. Further, for chemicals for which these values are not tabulated, the following equation may be used:~~

~~$$\log K_p = -2.80 + 0.66(\log K_{ow}) - 0.0056MW$$~~

~~where,~~

~~$K_{ow}$  = Octanol/water partition coefficient (dimensionless)~~

~~$MW$  = Molecular Weight (g/mole)~~

~~$K_p$  = Dermal permeability coefficient (cm/hr)~~

~~Note the  $MW$  and  $K_{ow}$  are presented in Table E-2.~~

~~For metals and inorganics, if no value is available, the permeability coefficient of  $1 \times 10^{-3}$  cm/hr is recommended as default value (USEPA, 2004). The permeability coefficient values are included in Table E-1. Footnotes indicate whether the value was calculated or obtained from the table.~~

## **E.4 PHYSICAL AND CHEMICAL PROPERTIES OF THE COCs**

Physical and chemical properties of the COCs are listed in Table E-2. These values must be used for all MRBCA evaluations unless there are justifiable reasons to modify these values and the department approves the alternative values. The use of different values would be allowed only under a Tier 3 risk assessment.

The following hierarchy was used to obtain the physical and chemical properties:

- (i) Missouri Department of Natural Resources, RBCA for Petroleum Storage Tanks,
- (ii) Missouri Department of Natural Resources, Cleanup Levels for Missouri (CALM),
- (iii) USEPA Region IX, PRG's Inter Calc Tables,
- (iv) Texas Commission on Environmental Quality (TCEQ), Texas Risk Reduction

Program (TRRP), and  
(v) Idaho Department of Environmental Quality (IDEQ), RBCA Tables.

Footnotes on Table E-2 indicate the source for each value.

## **E.5 EXPOSURE FACTORS**

A list of the exposure factors and the values that were used to develop generic Tier 1 risk-based target level values is presented in Table E-3. The exposure factors are typically estimated based on literature rather than site-specific measurements. For a Tier 3 risk assessment, site-specific exposure factors may be used with clear justification and the department's approval. For the evaluation of inhalation exposures, the values of both the exposure time (hours/day) and inhalation rate (cubic meters/day) are significant and interrelated.

A source of exposure factor information is USEPA's *Exposure Factors Handbook Volume 1 – General Factors* (August 1997). Other sources of exposure factor data may be used for Tier 3 risk assessment with approval of the department.

## **E.6 FATE AND TRANSPORT PARAMETERS**

Fate and transport parameters are necessary to estimate the target levels for the indirect routes of exposure. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate at a site. For a Tier 1 risk assessment, the department has selected typical conservative default values that are listed in Table E-4 for three generic vadose zone soil types. These include:

- soil type 1, representative of a sandy soil,
- soil type 2, representative of a silty soil, and
- soil type 3, representative of clayey soil.

For a Tier 2 risk assessment, a combination of site-specific and default fate and transport values may be used. However, the value of each parameter used, whether site-specific or default, must be justified based on site-specific conditions. Where site-specific conditions are significantly different from the Tier 1 assumptions, site-specific values should be used.

For a Tier 3 risk assessment, the specific fate and transport parameters required to calculate the target levels would depend on the model used.

## **E.7 MATHEMATICAL MODELS**

The input parameters mentioned above are used in two types of models, or equations, to calculate the risk-based target levels. These are the (i) uptake equations and (ii) fate and transport models. For Tier 1 and Tier 2 risk assessments, the department has selected the models and equations included in this appendix for use.

For Tier 2 risk assessments, the department requires the use of the same equations and models. With the prior approval of the department through the submittal of a Tier 3 work plan, a different set of models may be used for Tier 3 risk assessments.

## **E.8 TARGET LEVELS FOR PROTECTION OF GROUNDWATER**

A schematic of this pathway is shown in Figure E-1. If the groundwater use pathway is deemed to be complete under current or future conditions, it must be quantitatively evaluated as follows:

**Step 1:** Identify the critical point of exposure (POE). The POE is the nearest down-gradient, three-dimensional location that could reasonably be considered for installation of a groundwater supply well. Note that the POE need not necessarily be an actual existing well; the POE could be a hypothetical well. Further the POE may be screened in a deeper zone, and not necessarily the shallow most water bearing zone.

**Step 2:** Determine target levels at the POE. For COCs that have MCLs, the target level at the POE will be the MCL. For COCs that do not have MCLs, the target levels will be the risk-based calculated value that assumes groundwater ingestion and indoor inhalation of vapors emitted due to water use. Note that the indoor inhalation of vapors based on water use pathway will be considered only for volatile COCs (refer to Figure E-2).

**Step 3:** Identification of point of demonstration (POD) wells and calculation of target levels at the POD. POD wells are located between the source and the POE to monitor the COC concentrations in groundwater as a means of protecting against exceedances at the POE. Risk-based target concentrations will be developed for the POD using appropriate fate and transport models and site-specific parameters as explained in Section E-12.

**Step 4:** Calculation of representative soil COC concentrations in the area of release. Risk-based target levels for soil should also be calculated for the area of release using the equations and models presented in this appendix.

This step requires an evaluation of the dilution and attenuation of the COC in the unsaturated zone. For Tier 1 and Tier 2 evaluation, the following depth dependent unsaturated zone dilution attenuation factor (DAF) values were used:

Depth to groundwater less than 20 feet,	DAF = 1
Depth to groundwater 20-50 feet,	DAF = 2
Depth to groundwater >50 feet,	DAF = 4

Thus the quantitative evaluation of this pathway requires the calculation of target levels at the (i) POE, (ii) POD, and (iii) soil source. These concentrations must be compared with representative concentrations for this pathway.

## **E.9 TARGET LEVELS FOR PROTECTION OF SURFACE WATER BODIES**



Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected as per 10 CSR 20-7.031. Sampling for COCs in surface water bodies will be necessary when COC migration is known or suspected to adversely affect a surface water body.

### **E.9.1 Protection of Streams**

Protection of streams requires the (i) determination of stream classification, (ii) identification of the use designations of the stream, (iii) estimation of allowable COC concentrations in the stream, (iv) determination of stream 7Q10, and (v) calculation of allowable COC concentrations at various locations within the stream and the groundwater plume. The latter include:

- Instream COC concentrations at the downstream edge (and beyond) of a mixing zone ( $C_{sw}$ ),
- Instream COC concentrations at the downstream edge (and beyond) of the zone of initial dilution, if applicable ( $C_{zid}$ ),
- Groundwater COC concentrations at the point of discharge of the groundwater plume to the surface water body ( $C_{gw}$ ),
- Groundwater COC concentrations at points of demonstration at different distances between the source and the point of discharge ( $C_{pod}$ ), and
- Soil COC concentrations at the source area soils ( $C_{soil}$ ).

The locations of these various points are schematically shown in Figure E-3. Depending on site-specific conditions, sampling for COC concentrations at one or more of these locations may be necessary.

The procedure for protection of streams and surface waters is shown in Figure E-4 and discussed below:

**Step 1: Determine stream classification:** As per 10 CSR 20-7.031(1)(F), streams in Missouri are classified as Class C, Class P, or P1 waters. Stream classification applies to specific reaches of a stream and not necessarily to the entire stream length. Classification of streams and the length of the classified segment can be found in Table H of 10 CSR 20-7.031. Streams not included in Table H are unclassified (Class U) and have no assigned designated uses.

**Step 2: Determine the beneficial use designation(s) of the stream:** As per 10 CSR 20-7.031(1)(C), beneficial uses of a stream include one or more of the following:

- Irrigation (IRR),
- Livestock & wildlife watering (LWW),
- Protection of warm water aquatic life and human health – fish consumption (AQL),
- Cool water fishery (CLF),
- Cold water fishery (CDF),
- Whole body contact recreation (WBC),
- Boating and canoeing (BTG),
- Drinking water supply (DWS), and

- Industrial (IND).

Beneficial use designations for classified streams are tabulated in Table H of 10 CSR 20-7.031. A stream may have multiple beneficial use designations, in which case all beneficial uses must be identified.

**Step 3: Determine stream water quality criteria:** Stream water quality criteria depend on the beneficial use designation(s) of the stream and can be found in Table A of 10 CSR 20-7.031. For streams with multiple beneficial uses, select the most protective applicable criteria. For metals, the criteria for the protection of aquatic life depend on the hardness of water. For specific water quality criteria, refer to 10 CSR 20-7.031, Table A.

If COCs for which water quality criteria are not available are present at a site, contact the department's project manager for consultation with the Water Protection Program (WPP).

For Class C and Class P or P1 streams, water quality criteria must be met at the downstream edge of the mixing zone. As defined in 10 CSR 20-7.031(1)(N), a mixing zone is "an area of dilution of effluent in the receiving water beyond which chronic toxicity criteria must be met". For unclassified streams, applicable water quality criteria must be met at the point of groundwater discharge to the stream.

**Step 4: Determine 7Q10 and groundwater discharge:** The 7Q10 low-flow of a stream is the average minimum flow for seven consecutive days that has a probable recurrence interval of once-in-ten years. Estimation of 7Q10 must follow current practices as included in USGS and USEPA literature. The lowest value of 7Q10 that can be used as a default value for a Tier 1 risk assessment that includes Class C and Class P or P1 streams is 0.1 cubic feet per second (cfs). Unclassified streams have a default 7Q10 value of 0.0 cfs. Also, the volume of impacted groundwater discharging into the stream must be determined. This determination is based on the dimensions of the plume at the point of discharge and an average Darcy velocity at the point of discharge. For flow-regulated streams, contact the department's WPP for the estimation of 7Q10.

**Step 5: Estimate concentrations at the point of discharge:** The concentrations at the point of discharge can be estimated using mass balance considerations. For streams with a 7Q10 of 0.1 cfs or greater, the stream flow to be used in the calculation is 0.25 of the 7Q10 flow calculated in Step 4. The specific equations are included in Appendix E, Section E-12.

**Step 6: Estimate groundwater and soil concentrations:** Applicable COC concentrations for soil and groundwater can be back-calculated using the concept of DAFs. The specific equations, a combination of the Summer's and Domenico's models, are presented in Appendix E, Section E-12.

The soil and groundwater COC concentrations discussed above apply to the protection of surface water. Other routes of exposure from groundwater, such as inhalation of volatiles and ingestion of groundwater, must also be evaluated as part of the process. Therefore,

cleanup criteria based on these routes of exposure may result in allowable COC concentrations that are lower than those protective of a surface water body.

**Step 7: Other considerations:** In addition to specific water quality criteria, general water quality criteria must be met in waters of the state at all times, including mixing zones. General water quality criteria are discussed in 10 CSR 20-7.031(3).

In addition to meeting chronic water quality criteria at the downstream edge of the mixing zone, acute water quality criteria must be met as per the following:

- For Class C and unclassified streams, the acute criteria must be met at the point of discharge,
- For Class P and P1 streams, the acute criteria must be met at the edge of the zone of initial dilution and throughout the mixing zone, and
- For an unclassified stream that flows into a classified stream or becomes a classified stream downstream of the point of discharge, the acute criteria must be met at the point of groundwater discharge to the unclassified stream.

### **E.9.2 Protection of Lakes**

The above considerations also apply to lakes. However, the mixing zone can not exceed one-quarter ( $\frac{1}{4}$ ) of the lake width at the discharge point or one hundred feet (100 feet) from the point of discharge, whichever is less. A zone of initial dilution is not allowed in lakes.

## **E.10 TARGET LEVELS FOR LEAD**

Lead has a number of toxic effects, but the main target for lead toxicity is the nervous system. Young children are especially vulnerable from the standpoint of both exposure and toxicity. Certain behaviors, such as crawling and playing on the floor or ground, result in increased exposure, and the central nervous system of a young child is particularly susceptible because it is still developing. Chronic exposure to even low levels of lead that are not overly toxic can result in impaired mental development.

USEPA has developed a model [Integrated Exposure Uptake Biokinetic (IEUBK) Model] to predict the risk of elevated blood lead (PbB) in children under the age of seven that are exposed to environmental lead from various sources. The model predicts the probability that a child exposed to lead concentrations in a specified media will have a PbB level greater than 10 micrograms per deciliter ( $\mu\text{g/dL}$ ), the level associated with adverse health effects (USEPA, 1999).

Because of the greater vulnerability of children to exposure and toxicity, the primary concern in a residential setting is risk to children. In the non-residential scenario, children are not directly exposed, but fetuses carried by female workers can be exposed. The USEPA has developed an adult lead methodology (ALM) to assess risk in this scenario (USEPA, 1996). The methodology is limited in terms of exposure media (soil/dust). Specifically, the methodology estimates the PbB concentrations in fetuses

carried by women exposed to lead contaminated soils. Research is ongoing to develop a model capable of simulating multimedia exposures over the entire human lifetime. Until this model is developed, the department will require the use of IEUBK for residential and ALM for non-residential scenarios, if the responsible party chooses to perform a site-specific evaluation for lead and concentrations exceed the following generic levels:

Residential land use soil (direct contact with soil)	260 mg/kg
Non-residential land use soil (direct contact with soil)	660 mg/kg

The groundwater target level where domestic use of groundwater is a complete pathway is 0.015 mg/L.

The above soil concentrations do not account for leaching to groundwater. At sites where this pathway is complete or potentially complete, the department may require a site-specific analysis.

## **E.11 TARGET LEVEL CALCULATION FOR LNAPL/DNAPL**

The MRBCA process allows for the calculation of risk and target levels when LNAPL or DNAPL is present. Under this condition, the primary routes of exposure are (i) indoor inhalation for a residential or a non-residential receptor, and, (ii) if the domestic use of groundwater pathway is complete or potentially complete, the protection of a current or potential future point of exposure (POE) groundwater well. For these pathways, the key step is the calculation of the vapor concentration and the dissolved concentration emanating from the LNAPL/DNAPL. Once these concentrations have been estimated, risk and target levels can be determined using the procedures presented in Sections E.2 to E.9 above.

Soil Vapor Concentration: The soil vapor concentration in equilibrium with LNAPL/DNAPL is the effective soil vapor concentration. This concentration depends on (i) the chemical-specific saturated soil vapor concentration, and (ii) the mole fraction of the chemical in the LNAPL/DNAPL for which the soil vapor concentration is being calculated. If the mole fraction of a COC is not known, default mole fractions, calculated using the weight fraction of a specific COC in the LNAPL/DNAPL, may be used if the NAPL can be analyzed and its components determined. Alternatively, the evaluator may sample the LNAPL/DNAPL for laboratory analysis to determine site-specific values for the weight and mole fractions. The specific equations used to calculate the effective soil vapor or effective dissolved concentrations are presented in Section E.12.

In the forward model of risk assessment, the effective soil vapor and dissolved concentrations can be used to calculate the risk due to indoor inhalation or to estimate the concentration in the point of demonstration (POD) and POE wells. If DNAPL is located below the water table, pathways related to inhalation of vapors will be considered incomplete as vapors will not penetrate the overlying column of saturated soil.

## **REFERENCES**

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USEPA, 2003. Human Health Toxicity Values in Superfund Risk Assessments. OSWER Directive 9285.7-53. December 5, 2003.

## E.12 MODELS/EQUATIONS FOR ESTIMATING DTLs, TIER 1, AND TIER 2 TARGET LEVELS WITHIN THE MRBCA PROCESS

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**INDOOR INHALATION OF VAPORS  
(CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)**

Carcinogenic effects

$$RBTL_{ai} = \frac{TR \times BW \times AT_c \times 365}{IR_{ai} \times ET_{in} \times ED \times EF \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ai} \times ET_{in} \times ED \times EF}$$

Source: RAGS, Vol. I, Part A, 1989, p. 6-44

where:

- $RBTL_{ai}$  = Risk-based target level in indoor air [mg/m<sup>3</sup>]
- $TR$  = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
- $THQ$  = Target hazard quotient for individual constituents [-]
- $BW$  = Body weight [kg]
- $AT_c$  = Averaging time for carcinogens[year]
- $AT_{nc}$  = Averaging time for non-carcinogens[year]
- $IR_{ai}$  = Indoor inhalation rate [m<sup>3</sup>/hr]
- $ET_{in}$  = Indoor exposure time [hr/day]
- $ED$  = Exposure duration [year]
- $EF$  = Exposure frequency [day/year]
- $RfD_i$  = Chemical-specific inhalation reference dose [mg/kg-day]
- $SF_i$  = Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)<sup>-1</sup>]
- 365 = Converts  $AT_c$ ,  $AT_{nc}$  in years to days [day/year]

## OUTDOOR INHALATION OF VAPORS (CONSTRUCTION WORKER)

### Carcinogenic effects

$$RBTL_{ao} = \frac{TR \times BW \times AT_c \times 365}{IR_{ao} \times ET_{out} \times ED \times EF \times SF_i}$$

### Non-carcinogenic effects

$$RBTL_{ao} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ao} \times ET_{out} \times ED \times EF}$$

Source: RAGS, Vol. I, Part A, 1989, p. 6-44

where:

- $RBTL_{ao}$  = Risk-based target level in outdoor air [ $\text{mg}/\text{m}^3$ ]
- $TR$  = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
- $THQ$  = Target hazard quotient for individual constituents [-]
- $BW$  = Body weight [kg]
- $AT_c$  = Averaging time for carcinogens[year]
- $AT_{nc}$  = Averaging time for non-carcinogens[year]
- $IR_{ao}$  = Outdoor inhalation rate [ $\text{m}^3/\text{hr}$ ]
- $ET_{out}$  = Outdoor exposure time [hr/day]
- $ED$  = Exposure duration [year]
- $EF$  = Exposure frequency [day/year]
- $RfD_i$  = Chemical-specific inhalation reference dose [ $\text{mg}/\text{kg}\text{-day}$ ]
- $SF_i$  = Chemical-specific inhalation cancer slope or potency factor [ $(\text{mg}/\text{kg}\text{-day})^{-1}$ ]
- 365 = Converts  $AT_c$ ,  $AT_{nc}$  in years to days [day/year]



**DERMAL CONTACT WITH CHEMICALS IN WATER  
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)**

Carcinogenic effects

$$RBTL_{dw} = \frac{TR \times BW \times AT_c \times 365 \times 1000}{SF_d \times SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

Non-carcinogenic effects

$$RBTL_{dw} = \frac{THQ \times BW \times AT_{nc} \times 365 \times 1000 \times RfD_d}{SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

For organic chemicals,

If  $t_{event} \leq t^*$ , then  $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$

If  $t_{event} > t^*$ , then  $Z = FA \times K_p \left[ \frac{t_{event}}{1+B} + 2\tau_{event} \left( \frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals,  $Z = K_p \times t_{event}$

where:

- $RBTL_{dw}$  = Risk-based target level for dermal contact with groundwater [mg/L]
- $TR$  = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
- $THQ$  = Target hazard quotient for individual constituents [-]
- $BW$  = Body weight [kg]
- $AT_c$  = Averaging time for carcinogens[year]
- $AT_{nc}$  = Averaging time for non-carcinogens[year]
- $SA_{gw}$  = Skin surface area available for contact with water [cm<sup>2</sup>]
- $EV_{gw}$  = Event frequency [event/day]
- $ED$  = Exposure duration [year]
- $EF$  = Exposure frequency [day/year]
- $RfD_d$  = Chemical-specific dermal reference dose [mg/kg-day]
- $SF_d$  = Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)]<sup>-1</sup>
- $365$  = Converts  $AT_c$ ,  $AT_{nc}$  in years to days [day/year]
- $1000$  = Conversion factor from cm<sup>3</sup> to L [cm<sup>3</sup>/L]
- $t_{event}$  = Event duration [hr/event]
- $t^*$  = Chemical-specific time to reach steady-state [hr]
- $Z$  = Chemical-specific dermal factor [cm/event]
- $K_p$  = Chemical-specific dermal permeability coefficient [cm/hr]
- $FA$  = Chemical-specific fraction absorbed in water [-]
- $\tau_{event}$  = Chemical-specific lag time [hr/event]
- $B$  = Chemical-specific relative contribution of permeability coefficient [-]

$$B = K_p \frac{\sqrt{MW}}{2.6}$$

$$\log K_p = -2.80 + 0.66 \log K_{ow} - 0.0056 MW$$

If  $B < 0.6$  or  $B = 0.6$ , then,  $t^* = 2.4 \tau_{event}$

If  $B > 0.6$  then,  $t^* = 6 \tau_{event} \times (b - \sqrt{b^2 - c^2})$

where,

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)}$$

$$b = 2 \times \frac{(1 + B)^2}{\pi} - c$$

$$\tau_{event} = 0.105 \times 10^{(0.0056 MW)}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$MW$  = Molecular weight [g/mole]

$K_{ow}$  = Octanol water partition coefficient [L/kg]

$b, c$  = Correlation coefficient which have been fitted to the data from Flynn, G.L. (1990)

**DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)  
(ONLY FOR CHEMICALS WITHOUT MAXIMUM CONTAMINANT LEVELS)**

Carcinogenic effects

$$RBTL_w = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times \left[ (SF_o \times IR_w) + (SF_i \times ET \times K_f \times IR_a) + \left( \frac{SF_d}{1000} \times SA_{wb} \times EV_{wb} \times Z_{wb} \right) \right]}$$

Non-carcinogenic effects

$$RBTL_w = \frac{THQ \times BW \times AT_{nc} \times 365}{ED \times EF \times \left[ \left( \frac{I}{RfD_o} \times IR_w \right) + \left( \frac{1}{RfD_i} \times K_f \times ET \times IR_a \right) + \left( \frac{SA_{wb} \times EV_{wb} \times Z_{wb}}{RfD_d \times 1000} \right) \right]}$$

For organic chemicals,

$$\text{If } t_{wb-event} \leq t^*, \text{ then } Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$$

$$\text{If } t_{wb-event} > t^*, \text{ then } Z_{wb} = FA \times K_p \left[ \frac{t_{wb-event}}{1+B} + 2\tau_{event} \left( \frac{1+3B+3B^2}{(1+B)^2} \right) \right]$$

For inorganic chemicals,  $Z_{wb} = K_p \times t_{wb-event}$

Note:  $K_f = 0$  for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2 x 10<sup>-4</sup> or Henry's law constant (atm-m<sup>3</sup>/mol) < 1.5 x 10<sup>-5</sup>).

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H <sub>2</sub> O]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$BW$	=	Body weight [kg]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$IR_w$	=	Water ingestion rate [L/day]
$IR_a$	=	Indoor inhalation rate [m <sup>3</sup> /hr]
$ED$	=	Exposure duration [year]
$EF$	=	Exposure frequency [day/year]
$K_f$	=	Volatilization factor [L/m <sup>3</sup> ]
$ET$	=	Exposure time [hr/day]
$SA_{wb}$	=	Skin surface area available for whole-body contact with water [cm <sup>2</sup> ]
$EV_{wb}$	=	Event frequency for whole-body contact with water [event/day]
$RfD_o$	=	Chemical-specific oral reference dose [mg/kg-day]
$RfD_i$	=	Chemical-specific inhalation reference dose [mg/kg-day]
$RfD_d$	=	Chemical-specific dermal reference dose [mg/kg-day]
$SF_o$	=	Chemical-specific oral cancer slope or potency factor [mg/(kg-day)] <sup>-1</sup>
$SF_i$	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day) <sup>-1</sup> ]
$SF_d$	=	Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)] <sup>-1</sup>
365	=	Converts $AT_c$ , $AT_{nc}$ in years to days [day/year]
1000	=	Conversion factor from cm <sup>3</sup> to L [cm <sup>3</sup> /L]
$t_{wb-event}$	=	Event duration for whole-body contact [hr/event]
$t^*$	=	Chemical-specific time to reach steady-state [hr]
$Z_{wb}$	=	Chemical-specific dermal factor for whole-body contact [cm/event]
$K_p$	=	Chemical-specific dermal permeability coefficient [cm/hr]
$FA$	=	Chemical-specific fraction absorbed in water [-]
$\tau_{event}$	=	Chemical-specific lag time [hr/event]
$B$	=	Chemical-specific relative contribution of permeability coefficient [-]

**DERMAL CONTACT WITH CHEMICALS IN SOIL  
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)**

Carcinogenic effects

$$RBTL_{dcss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_d \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}$$

Non-carcinogenic effects

$$RBTL_{dcss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_d}{EF \times ED \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

- $RBTL_{dcss}$  = Risk-based target level for dermal contact of chemicals in surficial soil [mg/kg]
- $TR$  = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
- $THQ$  = Target hazard quotient for individual constituents [-]
- $BW$  = Body weight [kg]
- $AT_c$  = Averaging time for carcinogens [year]
- $AT_{nc}$  = Averaging time for non-carcinogens [year]
- $ED$  = Exposure duration [year]
- $EF$  = Exposure frequency [day/year]
- $SA_{soil}$  = Skin surface area available for contact with soil [cm<sup>2</sup>]
- $EV_{soil}$  = Event frequency [event/day]
- $AF$  = Soil to skin adherence factor [mg/cm<sup>2</sup>-event]
- $RAF_d$  = Chemical-specific dermal relative absorption factor [-]
- $SF_d$  = Dermal cancer slope factor [(mg/kg-day)<sup>-1</sup>]
- $RfD_d$  = Chemical-specific oral reference dose [mg/kg-day]
- $365$  = Converts  $AT_c$ ,  $AT_{nc}$  in years to days [day/year]

**INGESTION OF CHEMICALS IN SOIL  
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)**

Carcinogenic effects

$$RBTL_{ingss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_o \times 10^{-6} \times IR_{soil} \times RAF_o}$$

Non-carcinogenic effects

$$RBTL_{ingss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{EF \times ED \times 10^{-6} \times IR_{soil} \times RAF_o}$$

where:

- $RBTL_{ingss}$  = Risk-based target level for ingestion of chemicals in surficial soil [mg/kg]  
 $TR$  = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]  
 $THQ$  = Target hazard quotient for individual constituents [-]  
 $BW$  = Body weight [kg]  
 $AT_c$  = Averaging time for carcinogens [year]  
 $AT_{nc}$  = Averaging time for non-carcinogens [year]  
 $ED$  = Exposure duration [year]  
 $EF$  = Exposure frequency [day/year]  
 $IR_{soil}$  = Soil ingestion rate [mg/day]  
 $RAF_o$  = Oral relative absorption factor [-]  
 $SF_o$  = Oral cancer slope factor [(mg/kg-day)<sup>-1</sup>]  
 $365$  = Converts  $AT_c$ ,  $AT_{nc}$  in years to days [day/year]

## INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

### Carcinogenic effects

$$RBTL_{inhss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_i \times IR_{ao} \times ET_{out} \times (VF_{ss} + VF_p)}$$

### Non-carcinogenic effects

$$RBTL_{inhss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{EF \times ED \times ET_{out} \times IR_{ao} \times (VF_{ss} + VF_p)}$$

Note:  $VF_{ss} = 0$  for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) <  $4.2 \times 10^{-4}$  or Henry's law constant (atm-m<sup>3</sup>/mol) <  $1.5 \times 10^{-5}$ ).

where:

- $RBTL_{inhss}$  = Risk-based target level of inhalation of chemicals in surficial soil [mg/kg]
- $TR$  = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
- $THQ$  = Target hazard quotient for individual constituents [-]
- $BW$  = Body weight [kg]
- $AT_c$  = Averaging time for carcinogens [year]
- $AT_{nc}$  = Averaging time for non-carcinogens [year]
- $ED$  = Exposure duration [year]
- $EF$  = Exposure frequency [day/year]
- $IR_{ao}$  = Outdoor inhalation rate [m<sup>3</sup>/hr]
- $ET_{out}$  = Outdoor exposure time [hr/day]
- $SF_i$  = Inhalation cancer slope factor [(mg/kg-day)<sup>-1</sup>]
- $RfD_i$  = The chemical-specific inhalation reference dose [mg/kg-day]
- $VF_p$  = Volatilization factor for particulate emissions from surficial soil [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]
- $VF_{ss}$  = Volatilization factor for vapor emissions from surficial soil [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]
- 365 = Converts  $AT_c$ ,  $AT_{nc}$  in years to days [day/year]

*Note: The depth to surficial soil for a construction worker is up to the typical construction depth.*

**INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF  
CHEMICALS IN SOIL  
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)**

Carcinogenic effects

$$RBT L_{ss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times \left[ (SF_o \times 10^{-6} \times IR_{soil} \times RAF_o) + (SF_d \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d) + (SF_i \times IR_{ao} \times ET_{out} \times (VF_{ss} + VF_p)) \right]}$$

Non-carcinogenic effects

$$RBT L_{ss} = \frac{THQ \times BW \times AT_{nc} \times 365}{EF \times ED \times \left[ \frac{10^{-6} \times IR_{soil} \times RAF_o}{RfD_o} + \frac{10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}{RfD_d} + \frac{ET_{out} \times IR_{ao} \times (VF_{ss} + VF_p)}{RfD_i} \right]}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.



where:

$RBTL_{ss}$	=	Risk-based target level of surficial soil [mg/kg]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$BW$	=	Body weight [kg]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$ED$	=	Exposure duration [year]
$EF$	=	Exposure frequency [day/year]
$IR_{soil}$	=	Soil ingestion rate [mg/day]
$RAF_o$	=	Oral relative absorption factor [-]
$SA$	=	Skin surface area [cm <sup>2</sup> /day]
$EV_{soil}$	=	Event frequency [event/day]
$AF$	=	Soil to skin adherence factor [mg/cm <sup>2</sup> ]
$RAF_d$	=	Dermal relative adsorption factor [-]
$IR_{ao}$	=	Outdoor inhalation rate [m <sup>3</sup> /hr]
$ET_{out}$	=	Outdoor exposure time [hr/day]
$SF_o$	=	Oral cancer slope factor [(mg/kg-day) <sup>-1</sup> ]
$SF_i$	=	Inhalation cancer slope factor [(mg/kg-day) <sup>-1</sup> ]
$RfD_o$	=	The chemical-specific oral reference dose [mg/kg-day]
$RfD_i$	=	The chemical-specific inhalation reference dose [mg/kg-day]
$VF_p$	=	Volatilization factor for particulate emissions from surficial soil [(mg/m <sup>3</sup> -air)/(mg/kg-soil)]
$VF_{ss}$	=	Volatilization factor for vapor emissions from surficial soil [(mg/m <sup>3</sup> -air)/(mg/kg-soil)]
365	=	Converts $AT_c$ , $AT_{nc}$ in years to days [day/year]

## INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

### Carcinogenic effects

$$RBTL_{ai-adj} = \frac{TR \times AT_c \times 365}{IR_{ai-aa} \times SF_i}$$

### Non-carcinogenic effects

$$RBTL_{ai-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ai-aa}}$$

where:

$$IR_{ai-aa} = \frac{IR_{ai-c} \times ED_c \times EF_c \times ET_{i-c}}{BW_c} + \frac{IR_{ai-a} \times ED_a \times EF_a \times ET_{i-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part B, 1991

where:

$RBTL_{ai-adj}$	=	Age-adjusted risk-based target level in indoor air [mg/m <sup>3</sup> ]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$IR_{ai-aa}$	=	Age-adjusted indoor inhalation rate [m <sup>3</sup> /kg]
$IR_{ai-c}$	=	Resident child indoor inhalation rate [m <sup>3</sup> /hr]
$IR_{ai-a}$	=	Resident adult indoor inhalation rate [m <sup>3</sup> /hr]
$ED_c$	=	Exposure duration for child [year]
$ED_a$	=	Exposure duration for an adult [year]
$EF_c$	=	Exposure frequency for a child [day/year]
$EF_a$	=	Exposure frequency for an adult [day/year]
$ET_{i-c}$	=	Indoor exposure time for a child [hour/day]
$ET_{i-a}$	=	Indoor exposure time for an adult [hour/day]
$BW_c$	=	Resident child body weight [kg]
$BW_a$	=	Resident adult body weight [kg]
$RfD_i$	=	Chemical-specific inhalation reference dose [mg/kg-day]
$SF_i$	=	Chemical-specific inhalation cancer slope factor [mg/kg-day] <sup>-1</sup>
365	=	Conversion factor [day/year]

## DERMAL CONTACT WITH CHEMICALS IN WATER (AGE-ADJUSTED RESIDENT)

### Carcinogenic effects

$$RBTL_{dcw-adj} = \frac{TR \times AT_c \times 365 \times 1000}{SF_d \times (DC_{w-c} \times Z_c + DC_{w-a} \times Z_a)}$$

### Non-carcinogenic effects

$$RBTL_{dcw-adj} = \frac{THQ \times AT_{nc} \times 365 \times 1000 \times RfD_d}{DC_{w-c} \times Z_c + DC_{w-a} \times Z_a}$$

where :

$$DC_{w-c} = \frac{ED_c \times EF_c \times SA_{gw-c} \times EV_{gw-c}}{BW_c}$$

$$DC_{w-a} = \frac{ED_a \times EF_a \times SA_{gw-a} \times EV_{gw-a}}{BW_a}$$

For organic chemicals,

$$\text{If } t_{event} \leq t^*, \text{ then } Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$$

If  $t_{event} > t^*$ , then

$$Z = FA \times K_p \left[ \frac{t_{event}}{1+B} + 2\tau_{event} \left( \frac{1+3B+3B^2}{(1+B)^2} \right) \right]$$

For inorganic chemicals,  $Z = K_p \times t_{event}$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{dcw-adj}$	=	Age-adjusted risk-based target level for dermal contact with chemicals in groundwater [mg/L-water]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$RfD_d$	=	Chemical-specific dermal reference dose [mg/kg-day]
$SF_d$	=	Chemical-specific dermal cancer slope or potency factor [(mg/kg-day) <sup>-1</sup> ]
365	=	Converts $AT_c, AT_{nc}$ in years to days [day/year]
1000	=	Conversion factor from cm <sup>3</sup> to L [cm <sup>3</sup> /L]
$t_{event}$	=	Event duration [hr/event]
$t^*$	=	Chemical-specific time to reach steady-state [hr]
$K_p$	=	Chemical-specific dermal permeability coefficient [cm/hr]
$FA$	=	Chemical-specific fraction absorbed in water [-]
$\tau_{event}$	=	Chemical-specific lag time [hr/event]
$B$	=	Chemical-specific relative contribution of permeability coefficient [-]
$DC_{w-c}$	=	Child dermal contact rate with groundwater [cm <sup>2</sup> -event/kg]
$DC_{w-a}$	=	Adult dermal contact rate with groundwater [cm <sup>2</sup> -event/kg]
$EV_{gw-c}$	=	Resident child event frequency [event/day]
$EV_{gw-a}$	=	Resident adult event frequency [event/day]
$Z_c$	=	Resident child chemical-specific dermal factor [cm/event]
$Z_a$	=	Resident adult chemical-specific dermal factor [cm/event]
$SA_{gw-c}$	=	Resident child skin surface area available for contact with water [cm <sup>2</sup> ]
$SA_{gw-a}$	=	Resident adult skin surface area available for contact with water [cm <sup>2</sup> ]
$BW_c$	=	Resident child body weight [kg]
$BW_a$	=	Resident adult body weight [kg]
$ED_c$	=	Resident child exposure duration [year]
$ED_a$	=	Resident adult exposure duration [year]
$EF_c$	=	Exposure frequency for a child [day/year]
$EF_a$	=	Exposure frequency for an adult [day/year]

**DOMESTIC WATER USE (AGE-ADJUSTED RESIDENT)  
(ONLY FOR CHEMICALS WITHOUT MAXIMUM CONTAMINANT LEVELS)**

Carcinogenic effects

$$RBTL_{w-adj} = \frac{TR \times AT_c \times 365}{\left[ (SF_o \times IR_{w-aa}) + (SF_i \times K_f \times IR_{a-aa}) + \left( \frac{SF_d}{1000} \times (DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a}) \right) \right]}$$

Non-carcinogenic effects

$$RBTL_{w-adj} = \frac{THQ \times AT_{nc} \times 365}{\left[ \left( \frac{1}{RfD_o} \times IR_{w-aa} \right) + \left( \frac{1}{RfD_i} \times K_f \times IR_{a-aa} \right) + \left( \frac{(DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a})}{RfD_d \times 1000} \right) \right]}$$

where:

$$IR_{w-aa} = \frac{ED_c \times EF_c \times IR_{w-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{w-a}}{BW_a}$$

$$IR_{a-aa} = \frac{ED_c \times EF_c \times ET_c \times IR_{a-c}}{BW_c} + \frac{ED_a \times EF_a \times ET_a \times IR_{a-a}}{BW_a}$$

$$DC_{wb-c} = \frac{ED_c \times EF_c \times SA_{wb-c} \times EV_{wb-c}}{BW_c} \quad \text{and} \quad DC_{wb-a} = \frac{ED_a \times EF_a \times SA_{wb-a} \times EV_{wb-a}}{BW_a}$$

For organic chemicals,

$$\text{If } t_{wb-event} \leq t^*, \text{ then } Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$$

$$\text{If } t_{wb-event} > t^*, \text{ then } Z_{wb} = FA \times K_p \left[ \frac{t_{wb-event}}{1+B} + 2\tau_{event} \left( \frac{1+3B+3B^2}{(1+B)^2} \right) \right]$$

For inorganic chemicals,  $Z_{wb} = K_p \times t_{wb-event}$

Note:  $K_f = 0$  for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) <  $4.2 \times 10^{-4}$  or Henry's law constant (atm-m<sup>3</sup>/mol) <  $1.5 \times 10^{-5}$ ).

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{w-adj}$	=	Age-adjusted risk-based target level for ingestion of groundwater [mg/L-H <sub>2</sub> O]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$RfD_o$	=	Chemical-specific oral reference dose [mg/kg-day]
$RfD_d$	=	Chemical-specific dermal reference dose [mg/kg-day]
$SF_o$	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day) <sup>-1</sup> ]
$SF_i$	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day) <sup>-1</sup> ]
$SF_d$	=	Chemical-specific dermal cancer slope or potency factor [(mg/(kg-day)) <sup>-1</sup> ]
$IR_{w-aa}$	=	Age-adjusted groundwater ingestion rate [L/kg]
$IR_{w-c}$	=	Resident child groundwater ingestion rate [L/day]
$IR_{a-c}$	=	Resident child inhalation rate [m <sup>3</sup> /hr]

$IR_{w-a}$	=	Resident adult groundwater ingestion rate [L/day]
$IR_{a-a}$	=	Resident adult inhalation rate [m <sup>3</sup> /hr]
$DC_{wb-c}$	=	Child dermal whole-body contact rate with groundwater [cm <sup>2</sup> -event/kg]
$DC_{wb-a}$	=	Adult dermal whole-body contact rate with groundwater [cm <sup>2</sup> -event/kg]
$BW_c$	=	Resident child body weight [kg]
$BW_a$	=	Resident adult body weight [kg]
$ED_c$	=	Resident child exposure duration [year]
$ET_c$	=	Resident child exposure time [hr/day]
$ET_a$	=	Resident adult exposure time [hr/day]
$ED_a$	=	Resident adult exposure duration [year]
$EF_c$	=	Exposure frequency for a child [day/year]
$EF_a$	=	Exposure frequency for an adult [day/year]
$K_f$	=	Volatilization factor [L/m <sup>3</sup> ]
$SA_{wb}$	=	Skin surface area available for whole-body contact with water [cm <sup>2</sup> ]
$EV_{wb}$	=	Event frequency for whole-body contact with water [event/day]
365	=	Conversion factor [day/year]
1000	=	Conversion factor from cm <sup>3</sup> to L [cm <sup>3</sup> /L]
$t_{wb-event}$	=	Event duration for whole-body contact [hr/event]
$t^*$	=	Chemical-specific time to reach steady-state [hr]
$Z_{wb}$	=	Chemical-specific dermal factor for whole-body contact [cm/event]
$K_p$	=	Chemical-specific dermal permeability coefficient [cm/hr]
$FA$	=	Chemical-specific fraction absorbed in water [-]
$\tau_{event}$	=	Chemical-specific lag time [hr/event]
$B$	=	Chemical-specific relative contribution of permeability coefficient [-]



## DERMAL CONTACT WITH CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

### Carcinogenic effects

$$RBTL_{dcss-adj} = \frac{TR \times AT_c \times 365}{SF_d \times SA_{soil-aa} \times RAF_d \times 10^{-6}}$$

### Non-carcinogenic effects

$$RBTL_{dcss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_d}{SA_{soil-aa} \times RAF_d \times 10^{-6}}$$

where:

$$SA_{soil-aa} = \frac{ED_c \times EF_c \times AF_c \times SA_{soil-c} \times EV_{soil-c}}{BW_c} + \frac{ED_a \times EF_a \times AF_a \times SA_{soil-a} \times EV_{soil-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{dcss-adj}$	=	Age-adjusted risk-based target level for dermal contact with soil [mg/kg-wet soil]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$EF_c$	=	Exposure frequency for a child [day/year]
$EF_a$	=	Exposure frequency for an adult [day/year]
$RAF_d$	=	Dermal relative absorption factor [-]
$AF_c$	=	Resident child soil to skin adherence factor [mg/cm <sup>2</sup> -event]
$AF_a$	=	Resident adult soil to skin adherence factor [mg/cm <sup>2</sup> -event]
$RfD_d$	=	Chemical-specific dermal reference dose [(mg/kg-day)]
$SF_d$	=	Chemical-specific dermal cancer slope or potency factor [(mg/kg-day) <sup>-1</sup> ]
$SA_{aa}$	=	Age-adjusted skin surface area [mg/ kg]
$BW_c$	=	Resident child body weight [kg]
$BW_a$	=	Resident adult body weight [kg]
$ED_c$	=	Resident child exposure duration [year]
$ED_a$	=	Resident adult exposure duration [year]
$SA_{soil-c}$	=	Resident child skin surface area available for contact with soil [cm <sup>2</sup> /day]
$SA_{soil-a}$	=	Resident adult skin surface area available for contact with soil [cm <sup>2</sup> /day]
$EV_{soil-c}$	=	Resident child event frequency [event/day]
$EV_{soil-a}$	=	Resident Child event frequency [event/day]
365	=	Conversion factor [day/year]
$10^{-6}$	=	Conversion factor [kg/mg]

## INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

### Carcinogenic effects

$$RBTL_{ingss-adj} = \frac{TR \times AT_c \times 365}{SF_o \times IR_{s-aa} \times RAF_o \times 10^{-6}}$$

### Non-carcinogenic effects

$$RBTL_{ingss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_o}{IR_{s-aa} \times RAF_o \times 10^{-6}}$$

where :

$$IR_{s-aa} = \frac{ED_c \times EF_c \times IR_{s-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{s-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part A, 1989

where:

$RBTL_{ingss-adj}$	=	Risk-based target level for ingestion of soil [mg/kg-wet soil]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$RAF_o$	=	Oral relative absorption factor [-]
$RfD_o$	=	Chemical-specific oral reference dose [mg/kg-day]
$SF_o$	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day) <sup>-1</sup> ]
$IR_{s-aa}$	=	Age-adjusted soil ingestion rate [mg/kg]
$IR_{s-c}$	=	Resident child soil ingestion rate [mg/day]
$IR_{s-a}$	=	Resident adult soil ingestion rate [mg/day]
$BW_c$	=	Resident child body weight [kg]
$BW_a$	=	Resident adult body weight [kg]
$ED_c$	=	Resident child exposure duration [year]
$ED_a$	=	Resident adult exposure duration [year]
$EF_c$	=	Exposure frequency for a child [day/year]
$EF_a$	=	Exposure frequency for an adult [day/year]
365	=	Conversion factor [day/year]
$10^{-6}$	=	Conversion factor [kg/mg]

## INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

### Carcinogenic effects

$$RBTL_{ss-adj} = \frac{TR \times AT_c \times 365}{IR_{ao-aa} \times SF_i \times (VF_{ss} + VF_p)}$$

### Non-carcinogenic effects

$$RBTL_{ss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ao-aa} \times (VF_{ss} + VF_p)}$$

where:

$$IR_{ao-aa} = \frac{IR_{ao-c} \times ED_c \times EF_c \times ET_{o-c}}{BW_c} + \frac{IR_{ao-a} \times ED_a \times EF_a \times ET_{o-a}}{BW_a}$$

Note:  $VF_{ss} = 0$  for non-volatile chemicals (i.e., chemicals with a molecular weight  $> 200$  and Henry's law constant (dimensionless)  $< 4.2 \times 10^{-4}$  or Henry's law constant (atm-m<sup>3</sup>/mol)  $< 1.5 \times 10^{-5}$ ).

Source: Modified from RAGS, Vol. I, Part B, 1991

where:

$RBTL_{ss-adj}$	=	Age-adjusted risk-based target level in surficial soil [mg/kg]
$TR$	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$	=	Target hazard quotient for individual constituents [-]
$VF_{ss}$	=	Volatilization factor for vapor emissions from surficial soil [kg-soil/m <sup>3</sup> -air]
$VF_p$	=	Volatilization factor for particulate emissions from surficial soil [kg-soil/m <sup>3</sup> -air]
$IR_{ao-aa}$	=	Age-adjusted outdoor inhalation rate [m <sup>3</sup> /kg]
$IR_{ao-c}$	=	Resident child outdoor inhalation rate [m <sup>3</sup> /hr]
$IR_{ao-a}$	=	Resident adult outdoor inhalation rate [m <sup>3</sup> /hr]
$AT_c$	=	Averaging time for carcinogens [year]
$AT_{nc}$	=	Averaging time for non-carcinogens [year]
$ED_c$	=	Exposure duration for child [year]
$ED_a$	=	Exposure duration for an adult [year]
$EF_c$	=	Exposure frequency for a child [day/year]
$EF_a$	=	Exposure frequency for an adult [day/year]
$ET_{o-c}$	=	Outdoor exposure time for a child [hour/day]
$ET_{o-a}$	=	Outdoor exposure time for an adult [hour/day]
$RfD_i$	=	Chemical-specific inhalation reference dose [mg/kg-day]
$SF_i$	=	Chemical-specific inhalation cancer slope factor [(mg/kg-day) <sup>-1</sup> ]
365	=	Conversion factor [day/year]

## INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

### Carcinogenic effects

$$RBTL_{ss-combined} = \frac{TR \times AT_c \times 365}{(SF_o \times 10^{-6} \times IR_{s-aa} \times RAF_o) + (SF_d \times 10^{-6} \times SA_{soil-aa} \times RAF_d) + SF_i \times IR_{ao-aa} \times (VF_{ss} + VF_p)}$$

### Non-carcinogenic effects

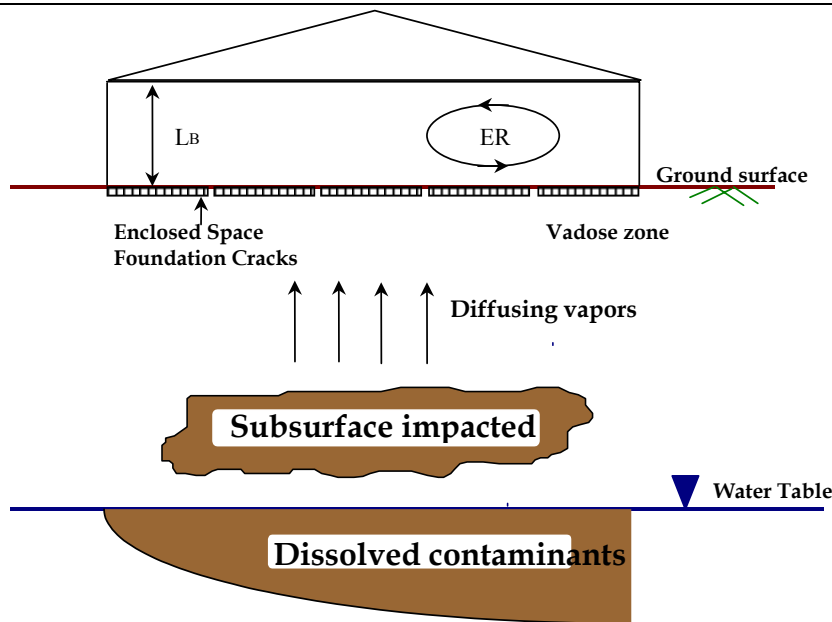
$$RBTL_{ss-combined} = \frac{THQ \times AT_{nc} \times 365}{\frac{1}{RfD_o} \times 10^{-6} \times IR_{s-aa} \times RAF_o + \frac{1}{RfD_d} \times 10^{-6} \times SA_{soil-aa} \times RAF_d + \frac{1}{RfD_i} \times IR_{ao-aa} \times (VF_{ss} + VF_p)}$$

Note: All parameters are defined under the individual pathway equations.

Note:  $VF_{ss} = 0$  for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) <  $4.2 \times 10^{-4}$  or Henry's law constant (atm-m<sup>3</sup>/mol) <  $1.5 \times 10^{-5}$ ).

Source: Modified from RAGS, Vol. I, Part E, 2004.

## SUBSURFACE SOIL VAPOR CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION



$$RBTL_{svi} = \frac{RBTL_{ai}}{VF_{sv}}$$

where:

$RBTL_{svi}$  = Risk-based target level for indoor inhalation of vapors from subsurface [ $\text{mg}/\text{m}^3\text{-air}$ ]

$RBTL_{ai}$  = Risk-based target level for indoor inhalation of air [ $\text{mg}/\text{m}^3\text{-air}$ ]

$VF_{sv}$  = Volatilization factor from subsurface soil vapor to indoor (enclosed space) air [-]

Source: ASTM E1739-95



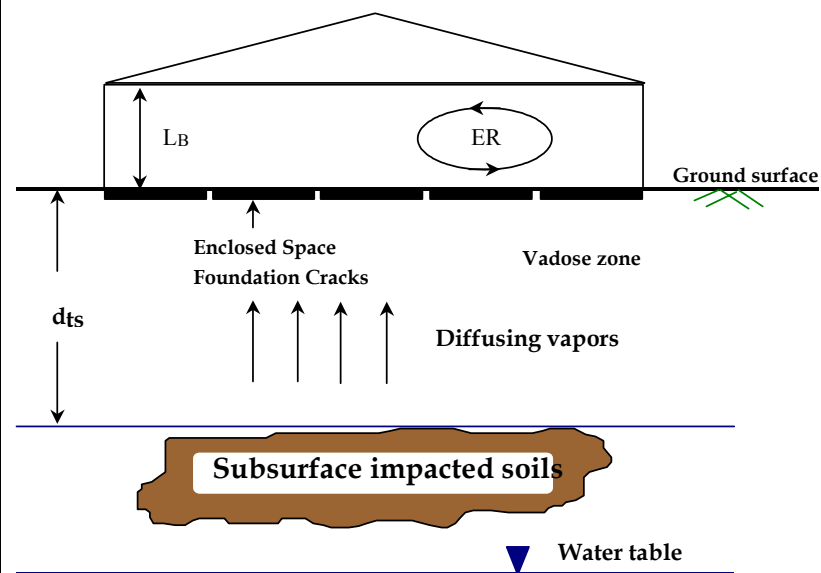
## SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{si} = \frac{RBTL_{ai}}{VF_{seep}}$$

where:

- $RBTL_{si}$  = Risk-based target level for indoor inhalation of vapors from subsurface soils [mg/kg-soil]  
 $RBTL_{ai}$  = Risk-based target level for indoor inhalation of air [mg/m<sup>3</sup>-air]  
 $VF_{seep}$  = Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]

Source: ASTM E1739-95



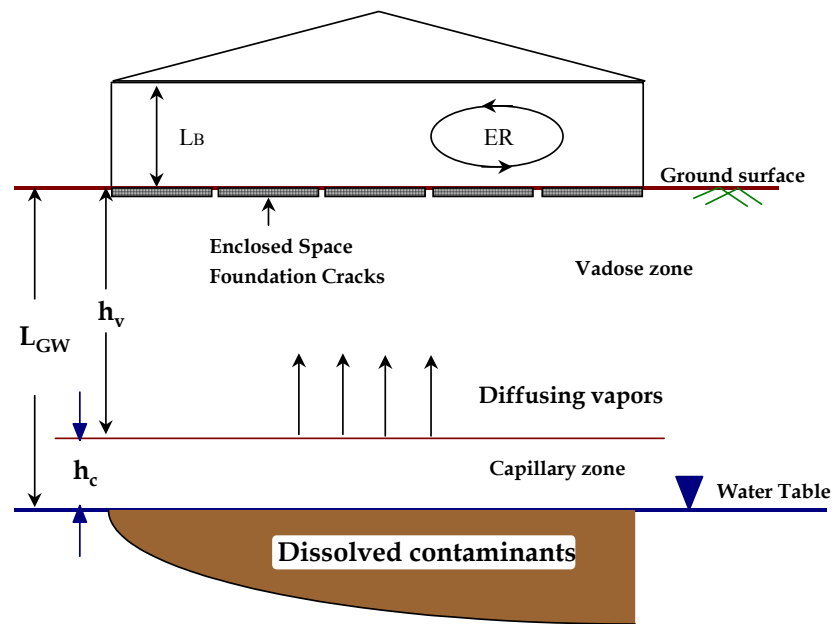
## GROUNDWATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ai}}{VF_{wesp}}$$

where:

- $RBTL_{wi}$  = Risk-based target level for indoor inhalation of vapors from groundwater [mg/L-water]
- $RBTL_{ai}$  = Risk-based target level for indoor inhalation of air (mg/m<sup>3</sup>-air)
- $VF_{wesp}$  = Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m<sup>3</sup>-air)/(mg/L-water)]

Source: ASTM E1739-95



## GROUNDWATER CONCENTRATIONS PROTECTIVE OF OUTDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ao}}{VF_{wamb}}$$

where:

- $RBTL_{wi}$  = Risk-based target level for indoor inhalation of vapors from groundwater [mg/L-water]
- $RBTL_{ao}$  = Risk-based target level for outdoor inhalation of air (mg/m<sup>3</sup>-air)
- $VF_{wamb}$  = Volatilization factor from groundwater to outdoor air [(mg/m<sup>3</sup>-air)/(mg/L-water)]

Source: ASTM E1739-95

## VOLATILIZATION FACTORS (SURFICIAL SOIL TO OUTDOOR AIR)

$$VF_{ss} = \left[ Q/C \times \frac{(3.14 \times D_A \times \tau)^{1/2}}{(2 \times \rho_s \times D_A)} \times 10^{-4} \right]^{-1}$$

where:

$$D_A = \frac{(\theta_{as}^{10/3} \times D^a \times H + \theta_{ws}^{10/3} \times D^w) / \theta_T^2}{\rho_s \times K_{sv} + \theta_{ws} + \theta_{as} \times H}$$

or

$$VF_{ss} = \frac{W_a \times \rho_s \times d_s}{U_m \times \delta_a \times \tau} \times 10^3$$

Use smaller of the two  $VF_{ss}$ .

Source: Soil Screening Guidance, 1996

where:

- $VF_{ss}$  = Volatilization factor from surficial soil to outdoor (ambient) air [kg-soil/m<sup>3</sup>-air]
- $Q/C$  = Inverse of the mean concentration at the center of square source [(g/m<sup>2</sup>-s)/(kg/m<sup>3</sup>)]
- $D_A$  = Apparent diffusivity [cm<sup>2</sup>/s]
- $\tau$  = Averaging time for vapor flux [s]
- $\rho_s$  = Vadose zone dry soil bulk density of surficial soil [g-soil/cm<sup>3</sup>-soil]
- $K_{sv}$  = Chemical-specific solid-water sorption coefficient [cm<sup>3</sup>-water/g-soil]
- $D^a$  = Chemical-specific diffusion coefficient in air [cm<sup>2</sup>/s]
- $D^w$  = Chemical-specific diffusion coefficient in water [cm<sup>2</sup>/s]
- $\theta_T$  = Total soil porosity in the surficial soils [cm<sup>3</sup>/cm<sup>3</sup>-soil]
- $\theta_{as}$  = Volumetric air content in the surficial soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]
- $\theta_{ws}$  = Volumetric water content in the surficial soils [cm<sup>3</sup>-water/cm<sup>3</sup>-soil]
- $H$  = Chemical-specific Henry's Law constant [(L-water)/(L-air)]
- $10^{-4}$  = Conversion factor [m<sup>2</sup>/cm<sup>2</sup>]
- $W_a$  = Dimension of soil source area parallel to wind direction [cm]
- $d_s$  = Depth to base of surficial soil zone [cm]
- $U_m$  = Mean annual wind speed [m/s]
- $\delta_a$  = Breathing zone height [cm]
- $10^3$  = Conversion factor [(cm<sup>3</sup>-kg)/(m<sup>3</sup>-g)]

*Note: Surficial soil properties are assumed same as the vadose zone properties.*

**VOLATILIZATION FACTORS  
(PARTICULAR EMISSIONS FROM SURFICIAL SOIL)**

$$VF_p = \left[ \frac{Q/C \times 3600}{0.036 \times (1 - V) \times (U_m/U_t)^3 \times F(x)} \right]^{-1}$$

Source: Soil Screening Guidance, 1996

where:

- $VF_p$  = Volatilization factor for particulate emissions from surficial soil [kg-soil/m<sup>3</sup>-air]
- $Q/C$  = Inverse of the mean concentration at the center of square source [(g/m<sup>2</sup>-s)/(kg/m<sup>3</sup>)]
- $V$  = Fraction of vegetative cover [-]
- $U_m$  = Mean annual wind speed [m/s]
- $U_t$  = Equivalent threshold value of wind speed at 7 m [m/s]
- $F(x)$  = Function dependent on  $U_m/U_t$  derived using Cowherd *et al.* 1985 [-]
- $0.036$  = Empirical constant [g/m<sup>2</sup>-hr]

**VOLATILIZATION FACTORS  
(SUBSURFACE SOIL VAPOR TO INDOOR AIR)**

$$VF_{sv} = \frac{\left[ \frac{D_s^{eff} / d_{sv}}{ER \times L_B} \right]}{1 + \left[ \frac{D_s^{eff} / d_{sv}}{ER \times L_B} \right] + \left[ \frac{D_s^{eff} / d_{sv}}{(D_{crack}^{eff} / L_{crack}) \times \eta} \right]}$$

Source: ASTM E1739-95

where:

- $VF_{sv}$  = Volatilization factor from subsurface soil vapor to indoor (enclosed space) air [-]
- $\theta_{ws}$  = Volumetric water content in vadose zone soils [cm<sup>3</sup>-water/cm<sup>3</sup>-soil]
- $\theta_{as}$  = Volumetric air content in vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]
- $d_{sv}$  = Depth to subsurface soil vapor samples taken [cm]
- $L_B$  = Enclosed space volume/infiltration area ratio [cm]
- $L_{crack}$  = Enclosed space foundation or wall thickness [cm]
- $ER$  = Enclosed space air exchange rate [1/s]
- $D_s^{eff}$  = Effective diffusion coefficient in soil based on vapor-phase concentration [cm<sup>2</sup>/s]
- $D_{crack}^{eff}$  = Effective diffusion coefficient through foundation cracks [cm<sup>2</sup>/s]
- $\eta$  = Area fraction of cracks in foundation and/or walls [cm<sup>2</sup>-cracks/ cm<sup>2</sup>-total area]

## VOLATILIZATION FACTORS (SUBSURFACE SOIL TO INDOOR AIR)

$$VF_{seep} = \frac{\frac{H \times \rho_s}{[\theta_{ws} + (K_{sv} \times \rho_s) + (H \times \theta_{as})]} \times \left[ \frac{D_s^{eff} / d_{ts}}{ER \times L_B} \right]}{1 + \left[ \frac{D_s^{eff} / d_{ts}}{ER \times L_B} \right] + \left[ \frac{D_s^{eff} / d_{ts}}{(D_{crack}^{eff} / L_{crack}) \times \eta} \right]} \times 10^3$$

Source: ASTM E1739-95

where:

- $VF_{seep}$  = Volatilization factor from subsurface soil to indoor (enclosed space) air [ $\text{m}^3\text{-air}/(\text{mg}/\text{kg}\text{-soil})$ ]
- $H$  = Chemical-specific Henry's Law constant [L-water/L-air]
- $\rho_s$  = Dry soil bulk density [ $\text{g}\text{-soil}/\text{cm}^3\text{-soil}$ ]
- $\theta_{ws}$  = Volumetric water content in vadose zone soils [ $\text{cm}^3\text{-water}/\text{cm}^3\text{-soil}$ ]
- $K_{sv}$  =  $f_{ocv} \times K_{oc}$   
= Chemical-specific soil-water sorption coefficient in vadose zone [ $\text{cm}^3\text{-water}/\text{g}\text{-soil}$ ]
- $\theta_{as}$  = Volumetric air content in vadose zone soils [ $\text{cm}^3\text{-air}/\text{cm}^3\text{-soil}$ ]
- $d_{ts}$  = Depth to subsurface soil sources [cm]
- $L_B$  = Enclosed space volume/infiltration area ratio [cm]
- $L_{crack}$  = Enclosed space foundation or wall thickness [cm]
- $ER$  = Enclosed space air exchange rate [1/s]
- $D_s^{eff}$  = Effective diffusion coefficient in soil based on vapor-phase concentration [ $\text{cm}^2/\text{s}$ ]
- $D_{crack}^{eff}$  = Effective diffusion coefficient through foundation cracks [ $\text{cm}^2/\text{s}$ ]
- $\eta$  = Area fraction of cracks in foundation and/or walls [ $\text{cm}^2\text{-cracks}/\text{cm}^2\text{-total area}$ ]
- $10^3$  = Conversion factor [ $(\text{cm}^3\text{-kg})/(\text{m}^3\text{-g})$ ]

## VOLATILIZATION FACTORS (GROUNDWATER TO INDOOR AIR)

$$VF_{wesp} = \frac{H \times \left[ \frac{D_{ws}^{eff} / L_{GW}}{ER \times L_B} \right]}{1 + \left[ \frac{D_{ws}^{eff} / L_{GW}}{ER \times L_B} \right] + \left[ \frac{D_{ws}^{eff} / L_{GW}}{(D_{crack}^{eff} / L_{crack}) \times \eta} \right]} \times 10^3$$

Source: ASTM E1739-95

where:

- $VF_{wesp}$  = Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m<sup>3</sup>-air)/(mg/L-water)]
- $H$  = Vadose zone chemical specific Henry's Law constant [(L-water)/(L-air)]
- $L_{GW}$  = Depth to groundwater [cm]
- $L_B$  = Enclosed space volume/infiltration area ratio [cm]
- $L_{crack}$  = Enclosed space foundation or wall thickness [cm]
- $ER$  = Enclosed space air exchange rate [1/s]
- $D_{ws}^{eff}$  = Effective diffusion coefficient between groundwater and soil surface [cm<sup>2</sup>/s]
- $D_{crack}^{eff}$  = Effective diffusion coefficient through foundation cracks [cm<sup>2</sup>/s]
- $\eta$  = Area fraction of cracks in foundation and/or walls [cm<sup>2</sup>-cracks/ cm<sup>2</sup>-total area]
- $10^3$  = Conversion factor [L/m<sup>3</sup>]



### VOLATILIZATION FACTORS (GROUNDWATER TO OUTDOOR AIR)

$$VF_{wamb} = \frac{H}{1 + \left( \frac{100 \times U_m \times \delta_a \times L_{GW}}{W_{ga} \times D_{ws}^{eff}} \right)} \times 10^3$$

where:

- $VF_{wamb}$  = Volatilization factor from groundwater to outdoor air [(mg/m<sup>3</sup>-air)/(mg/L-water)]
- $H$  = Vadose zone chemical specific Henry's Law constant [(L-water)/(L-air)]
- $U_m$  = Mean annual wind speed [m/s]
- $\delta_a$  = Breathing zone height [cm]
- $L_{GW}$  = Depth to groundwater [cm]
- $D_{ws}^{eff}$  = Effective diffusion coefficient between groundwater and soil surface [cm<sup>2</sup>/s]
- $W_{ga}$  = Dimension of soil source area parallel to wind direction [cm]
- 100 = Conversion factor [cm/m]
- $10^3$  = Conversion factor [L/m<sup>3</sup>]

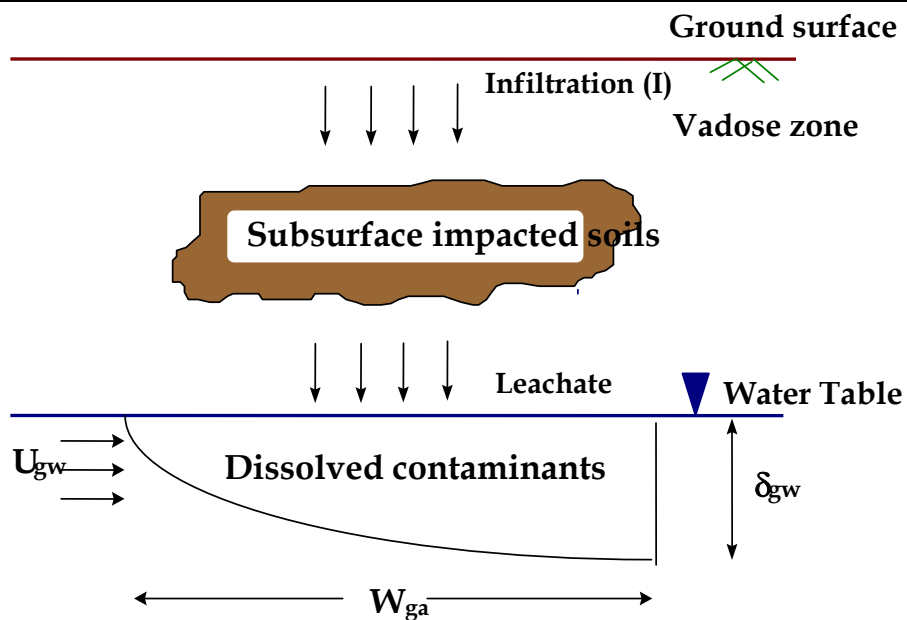
Source: ASTM E1739-95

## EFFECTIVE DIFFUSION COEFFICIENTS

<p><math>D_s^{eff}</math> : effective diffusion coefficient in soil based on vapor-phase concentration [cm<sup>2</sup>/s]</p> $D_s^{eff} = D^a \times \frac{\theta_{as}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{ws}^{3.33}}{\theta_T^2}$ <p>where:</p> <p><math>D^a</math> = Chemical-specific diffusion coefficient in air [cm<sup>2</sup>/s]  <math>D^w</math> = Chemical-specific diffusion coefficient in water [cm<sup>2</sup>/s]  <math>\theta_{as}</math> = Volumetric air content in vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]  <math>\theta_{ws}</math> = Volumetric water content in vadose zone soils [cm<sup>3</sup>-water/cm<sup>3</sup>-soil]  <math>\theta_T</math> = Total soil porosity in the impacted zone [cm<sup>3</sup>/cm<sup>3</sup>-soil]  <math>H</math> = Chemical-specific Henry's Law constant [L-water/L-air]</p>	<p><math>D_{ws}^{eff}</math> : effective diffusion coefficient between groundwater and surface soil [cm<sup>2</sup>/s]</p> $D_{ws}^{eff} = (h_{cap} + h_v) \times \left[ \frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$ <p>where:</p> <p><math>h_{cap}</math> = Thickness of capillary fringe [cm]  <math>h_v</math> = Thickness of vadose zone [cm]  <math>D_{cap}^{eff}</math> = Effective diffusion coefficient through capillary fringe [cm<sup>2</sup>/s]  <math>D_s^{eff}</math> = Effective diffusion coefficient in soil based on vapor-phase concentration [cm<sup>2</sup>/s]  <math>L_{GW}</math> = Depth to groundwater (<math>h_{cap} + h_v</math>) [cm]</p>
<p><math>D_{cap}^{eff}</math> : effective diffusion coefficient for the capillary fringe [cm<sup>2</sup>/s]</p> $D_{cap}^{eff} = D^a \times \frac{\theta_{acap}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{wcap}^{3.33}}{\theta_T^2}$ <p>where:</p> <p><math>D^a</math> = Chemical-specific diffusion coefficient in air [cm<sup>2</sup>/s]  <math>D^w</math> = Chemical-specific diffusion coefficient in water [cm<sup>2</sup>/s]  <math>\theta_{acap}</math> = Volumetric air content in capillary fringe soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]  <math>\theta_{wcap}</math> = Volumetric water content in capillary fringe soils [cm<sup>3</sup>-water/cm<sup>3</sup>-soil]  <math>\theta_T</math> = Total soil porosity [cm<sup>3</sup>/cm<sup>3</sup>-soil]  <math>H</math> = Chemical-specific Henry's Law constant [L-water/L-air]</p>	<p><math>D_{crack}^{eff}</math> : effective diffusion coeff. through foundation cracks [cm<sup>2</sup>/s]</p> $D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$ <p>where:</p> <p><math>D^a</math> = Chemical-specific diffusion coefficient in air [cm<sup>2</sup>/s]  <math>D^w</math> = Chemical-specific diffusion coefficient in water [cm<sup>2</sup>/s]  <math>\theta_{acrack}</math> = Volumetric air content in foundation/wall cracks [cm<sup>3</sup>-air/cm<sup>3</sup>-total volume]  <math>\theta_{wcrack}</math> = Volumetric water content in foundation/wall cracks [cm<sup>3</sup>-water/cm<sup>3</sup>-total volume]  <math>\theta_T</math> = Total soil porosity [cm<sup>3</sup>/cm<sup>3</sup>-soil]  <math>H</math> = Chemical-specific Henry's Law constant [L-water/L-air]</p>

Source: ASTM E1739-95

## SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER



$$RBTL_{SL} = \frac{RBTL_w}{LF_{SW}}$$

where:

- $RBTL_{SL}$  = Risk-based target level for leaching to groundwater from subsurface soil [mg/kg-soil]
- $RBTL_w$  = Risk-based target level for ingestion of groundwater [mg/L-water]
- $LF_{SW}$  = Leaching Factor (from subsurface soil to groundwater) [(mg/L-water)/(mg/kg-soil)]

Source: ASTM E1739-95

## LEACHING FACTOR FROM SUBSURFACE SOIL TO GROUNDWATER

$$LF_{SW} = \frac{\rho_s}{[\theta_{ws} + K_{sv} \times \rho_s + H \times \theta_{as}] \times \left( 1 + \frac{U_{gw} \times \delta_{gw}}{I \times W_{ga}} \right)}$$

where:

- $LF_{SW}$  = Leaching factor from subsurface soil to groundwater [(mg/L-water)/(mg/kg-soil)]
- $\rho_s$  = Vadose zone dry soil bulk density [g-soil/cm<sup>3</sup>-soil]
- $\theta_{ws}$  = Volumetric water content in vadose zone soils [cm<sup>3</sup>-water/cm<sup>3</sup>-soil]
- $K_{sv}$  =  $f_{ocv} \times K_{oc}$  = Chemical-specific soil-water sorption coefficient in vadose zone [cm<sup>3</sup>-water/g-soil]
- $H$  = Chemical-specific Henry's Law constant [L-water/L-air]
- $\theta_{as}$  = Volumetric air content in the vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]
- $U_{gw}$  =  $Ki$  = Groundwater Darcy velocity [cm/yr]
- $K$  = Hydraulic conductivity of the saturated zone [cm/year]
- $i$  = Hydraulic gradient in the saturated zone [-]
- $\delta_{gw}$  = Groundwater mixing zone thickness [cm]
- $I$  = Infiltration rate of water through vadose zone [cm/year]
- $W_{ga}$  = Groundwater dimension parallel to groundwater flow direction [cm]

This equation consists of two parts (i) the Summer's model and (ii) equilibrium conversion of the leachate concentration to a soil concentration on a dry weight basis.

Source: ASTM E1739-95

## SOIL CONCENTRATION AT WHICH DISSOLVED PORE WATER AND VAPOR PHASES BECOME SATURATED

### Single Component

$$C_s^{SAT} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \times \rho_s]$$

### Multiple Components

$$C_s^{SAT} = \frac{S_{ei}}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \times \rho_s]$$

where:

- $C_s^{SAT}$  = Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]
- $S$  = Pure component solubility in water [mg/L-water]
- $S_{ei}$  = Effective solubility of component  $i$  in water =  $x_i \times S$  [mg/L-water]
- $x_i$  = Mole fraction of component  $i$  =  $(w_i \times MW_{avg})/MW_i$  [-]
- $w_i$  = Weight fraction of component  $i$  [-]
- $MW_{avg}$  = Average molecular weight of mixture [g/mole]
- $MW_i$  = Molecular weight of component  $i$  [g/mole]
- $\rho_s$  = Vadose zone dry soil bulk density [g-soil/cm<sup>3</sup>-soil]
- $H$  = Chemical-specific Henry's Law constant [L-water/L-air]
- $\theta_{as}$  = Volumetric air content in the vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]
- $\theta_{ws}$  = Volumetric water content in vadose zone soils [cm<sup>3</sup>-water/cm<sup>3</sup>-soil]
- $K_{sv}$  =  $f_{ocv} \times K_{oc}$  = Chemical-specific soil-water sorption coefficient in vadose zone [cm<sup>3</sup>-water/g-soil]
- $f_{ocv}$  = Fraction organic carbon in vadose zone [g-C/g-soil]

Source: ASTM E1739-95

## SOIL VAPOR CONCENTRATION AT WHICH VAPOR PHASE BECOMES SATURATED

### Single Component

$$C_v^{SAT} = \frac{P^s \times MW}{R \times T} \times 10^6$$

### Multiple Components

$$C_v^{SAT} = \frac{x_i \times P_i^s \times MW_i}{R \times T} \times 10^6$$

where:

- $C_v^{SAT}$  = Soil vapor concentration at which vapor phase become saturated [mg/m<sup>3</sup>-air]
- $P^s$  = Saturated vapor pressure [atm]
- $P_i^s$  = Effective vapor pressure of component  $i$  in water =  $x_i \times P^s$  [atm]
- $R$  = Ideal gas constant [0.08206 atm•L/mol•K]
- $T$  = Temperature [K]
- $S_{ei}$  = Effective solubility of component  $i$  in water =  $x_i \times S$  [mg/L-water]
- $x_i$  = Mole fraction of component  $i$  =  $(w_i \times MW_{avg})/MW_i$  [-]
- $w_i$  = Weight fraction of component  $i$  [-]
- $MW_{avg}$  = Average molecular weight of mixture [g/mole]
- $MW_i$  = Molecular weight of component  $i$  [g/mole]
- $\rho_s$  = Vadose zone dry soil bulk density [g-soil/cm<sup>3</sup>-soil]
- $10^6$  = Conversion factor [(g/L)/(mg/m<sup>3</sup>)]

Source: ASTM E1739-95

## DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8) \exp \left[ \frac{x}{2\alpha_x} \left[ 1 - \sqrt{1 + \frac{4\lambda\alpha_x}{v}} \right] \right] \times \operatorname{erfc} \left[ \frac{(x-vt) \sqrt{1 + \frac{4\lambda\alpha_x}{v}}}{2\sqrt{\alpha_x \times v \times t}} \right] \times \left[ \operatorname{erf} \left[ \frac{(y+Y/2)}{2\sqrt{\alpha_y x}} \right] - \operatorname{erf} \left[ \frac{(y-Y/2)}{2\sqrt{\alpha_y x}} \right] \right] \times \left[ \operatorname{erf} \left[ \frac{(z+Z)}{2\sqrt{\alpha_z x}} \right] - \operatorname{erf} \left[ \frac{(z-Z)}{2\sqrt{\alpha_z x}} \right] \right]$$

where:

- $C$  = Dissolved-phase concentration [mg/L]
- $C_o$  = Dissolved-phase concentration at the source (at  $x=y=z=0$ ) [mg/L]
- $v$  = Retarded seepage velocity [m/sec]
- $\lambda$  = Overall first order bio-decay rate [1/day]
- $\alpha_x$  = Longitudinal dispersivity [m]
- $\alpha_y$  = Lateral dispersivity [m]
- $\alpha_z$  = Vertical dispersivity [m]
- $x, y, z$  = Spatial coordinates [m]
- $t$  = Time [day]
- $x$  = Distance along the centerline measured from the downgradient edge of the groundwater source [m]
- $Y$  = GW source dimension perpendicular to GW flow direction [m]
- $Z$  = GW source (mixing zone) thickness [m]
- $DAF_{sat} = C_o/C(x)$

At the centerline, for steady-state (after a long time) the concentration can be obtained by setting  $y = 0, z = 0$ , and  $x \ll v \times t$  as:

$$\frac{C(x)}{C_o} = \exp \left[ \frac{x}{2\alpha_x} \left[ 1 - \sqrt{1 + \frac{4\lambda\alpha_x}{v}} \right] \right] \times \operatorname{erf} \left[ \frac{Y}{4\sqrt{\alpha_y x}} \right] \times \operatorname{erf} \left[ \frac{Z}{2\sqrt{\alpha_z x}} \right]$$

At the centerline, for steady-state the concentration without decay can be obtained by setting  $y = 0, z = 0, x \ll vt$ , and  $\lambda = 0$  as:

$$\frac{C(x)}{C_o} = \operatorname{erf} \left[ \frac{Y}{4\sqrt{\alpha_y x}} \right] \times \operatorname{erf} \left[ \frac{Z}{2\sqrt{\alpha_z x}} \right]$$

Note: Compare to ASTM E1739-95, p. 31, where  $Y = S_w, Z = S_d, v = u$ , and  $C_o = C_{source}$

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)

## ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

Allowable soil concentration at the source [mg/kg] = Target groundwater concentration at the POE  $\times \frac{DAF_{POE}}{LF_{SW}} \times DAF_{unsat}$

Allowable groundwater concentration at the POD [mg/L] = Target groundwater concentration at the POE  $\times \frac{DAF_{POE}}{DAF_{POD}}$

where:

$POE$  = Point of exposure

$POD$  = Point of demonstration

$DAF_{POE}$  = Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation

$DAF_{POD}$  = Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation

$DAF_{unsat}$  = Dilution attenuation factor in the unsaturated zone

$LF_{SW}$  = Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

Concentration at POE is expressed in mg/L-water. Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

$$\text{First order decay rate [1/day]} = \frac{0.693}{\text{Half Life}}; \quad v = \frac{Ki}{\theta_{TS} R_s}$$

$$\text{Retardation factor for organics in the saturated zone } (R_s) = 1 + \left( \frac{\rho_{ss} \times K_{ss}}{\theta_{TS}} \right), \quad K_{ss} = f_{ocs} \times K_{oc} \text{ (for organics only)}$$

where:

$v$  = Regarded seepage velocity [cm/year]

$K$  = Hydraulic conductivity in saturated zone [cm/year]

$i$  = Hydraulic gradient in saturated zone [-]

$\rho_{ss}$  = Saturated zone dry soil bulk density [g-soil/cm<sup>3</sup>-soil]

$K_{ss}$  = Chemical-specific soil-water sorption coefficient in the saturated zone [cm<sup>3</sup>-water/g-soil]

$K_{oc}$  = Chemical-specific normalized partition coefficient [cm<sup>3</sup>/g-C]

$\theta_{TS}$  = Total porosity in the saturated zone [cm<sup>3</sup>/g-C]

$f_{ocs}$  = Fractional organic carbon content in the saturated zone [g-C/g-soil]



# ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION PROTECTIVE OF INDOOR INHALATION FOR RESIDENT AND NON-RESIDENTIAL WORKER

Allowable soil concentration at the source [mg/kg] = Target groundwater concentration below on/off - site building  $\times \frac{DAF_{bldg}}{LF_{SW}} \times DAF_{unsat}$

Allowable groundwater concentration at the POD [mg/L] = Target groundwater concentration below on/off - site building  $\times \frac{DAF_{bldg}}{DAF_{POD}}$

where:

$POD$  = Point of demonstration

$DAF_{bldg}$  = Dilution attenuation factor between the on/off-site building and source estimated using Domenico's equation

$DAF_{POD}$  = Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation

$DAF_{unsat}$  = Dilution attenuation factor in the unsaturated zone

$LF_{SW}$  = Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

Concentration below on/off-site building is expressed in mg/L-water

## STREAM PROTECTION: ALLOWABLE GROUNDWATER CONCENTRATION AT THE POINT OF DISCHARGE

$$C_{gw} = \frac{C_{sw}(Q_{gw} + Q_{sw})}{Q_{gw}} - C_{su} \left( \frac{Q_{sw}}{Q_{gw}} \right)$$

$$Q_{gw} = (Z + \sqrt{\alpha_z X_s}) \times (Y + 2\sqrt{\alpha_y X_s}) \times U_{gw}$$

where:

$Q_{gw}$	=	Impacted groundwater discharge into the stream [ft <sup>3</sup> /day]
$C_{gw}$	=	Allowable concentration in groundwater at the point of discharge into the stream [mg/L]
$Q_{sw}$	=	Stream flow upstream of the point of groundwater discharge (stream flow rate) [ft <sup>3</sup> /day]
$C_{sw}$	=	Allowable concentration at the downstream edge of the stream's mixing zone, i.e., the applicable stream water quality criteria [mg/L]
$C_{su}$	=	The COCs' concentration upstream of the groundwater plume discharge [mg/L]
$Y$	=	GW source dimension perpendicular to GW flow direction [ft]
$Z$	=	GW source (mixing zone) thickness [ft]
$\alpha_y$	=	Lateral dispersivity [ft]
$\alpha_z$	=	Vertical dispersivity [ft]
$X_s$	=	Distance from the downgradient edge of the groundwater source to the stream [ft]
$U_{gw}$	=	Darcy velocity [ft/day]

## STREAM PROTECTION: ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION AT THE SOURCE & POD

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target concentration at the POE [mg/L]} \times \frac{DAF_{POE}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target concentration at the POE [mg/L]} \times \frac{DAF_{POE}}{DAF_{POD}}$$

where:

$POE$	=	Point of exposure
$POD$	=	Point of demonstration
$DAF_{POE}$	=	Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation
$DAF_{POD}$	=	Dilution attenuation factor between the point of demonstration and the source estimated using Domenico's equation
$DAF_{unsat}$	=	Dilution attenuation factor in the unsaturated zone
$LF_{SW}$	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

For calculation of  $DAF_{POE}$  and  $DAF_{POD}$ , please refer to Domenico's model.

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**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor				Reference Dose				Absorption Factor				
		Oral, SF <sub>o</sub>	Inhalation, SF <sub>i</sub>	Dermal, SF <sub>d</sub>	Oral, RfD <sub>o</sub>	Inhalation, RfD <sub>i</sub>	Dermal, RfD <sub>d</sub>	Dermal, RA <sub>d</sub>	Oral, RA <sub>o</sub>					
		(mg/kg-day) <sup>-1</sup>	(mg/kg-day) <sup>-1</sup>	(mg/kg-day) <sup>-1</sup>	(mg/kg-day)	(mg/kg-day)	(mg/kg-day)	(unitless)	(unitless)					
VOCs														
Acetone	67-64-1					9.0E-01	<i>i</i>	9.0E-01	<i>r</i>	9.0E-01	0.1	<i>RA</i>	1.0	
Acetonitrile	75-05-8					1.7E-02	<i>r</i>	1.7E-02	<i>i</i>	1.7E-02	0.1	<i>RA</i>	1.0	
Acrylonitrile	107-13-1	5.4E-01	<i>i</i>	2.4E-01	<i>i</i>	5.4E-01	1.0E-03	<i>t</i>	5.7E-04	<i>i</i>	1.0E-03	0.1	<i>RA</i>	1.0
Allyl alcohol	107-18-6					5.0E-03	<i>i</i>	5.0E-03	<i>r</i>	5.0E-03	0.1	<i>RA</i>	1.0	
Allyl chloride	107-05-1	2.1E-02	<i>c</i>	2.1E-02	<i>c</i>	2.1E-02	2.9E-04	<i>r</i>	2.9E-04	<i>i</i>	2.9E-04	0.1	<i>RA</i>	1.0
Benzene	71-43-2													
1,1-Biphenyl	92-52-4					5.0E-02	<i>i</i>	5.0E-02	<i>r</i>	5.0E-02	0.1	<i>RA</i>	1.0	
Bis(chloromethyl)ether	542-88-1	2.2E+02	<i>i</i>	2.2E+02	<i>i</i>	2.2E+02					0.1	<i>RA</i>	1.0	
Bromochloromethane	74-97-5					4.0E-02	<i>t</i>	1.429E-02	<i>t</i>	4.0E-02	0.1	<i>RA</i>	1.0	
Bromodichloromethane	75-27-4	6.2E-02	<i>i</i>	1.3E-01	<i>c</i>	6.2E-02	2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0
Bromoform	75-25-2	7.9E-03	<i>i</i>	3.9E-03	<i>i</i>	7.9E-03	2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0
Bromomethane	74-83-9					1.4E-03	<i>i</i>	1.4E-03	<i>i</i>	1.4E-03	0.1	<i>RA</i>	1.0	
n-Butylbenzene	104-51-8					4.0E-02	<i>n</i>	4.0E-02	<i>r</i>	4.0E-02	0.1	<i>RA</i>	1.0	
sec-Butylbenzene	135-98-8					4.0E-02	<i>n</i>	4.0E-02	<i>r</i>	4.0E-02	0.1	<i>RA</i>	1.0	
tert-Butylbenzene	98-06-6					4.0E-02	<i>n</i>	4.0E-02	<i>r</i>	4.0E-02	0.1	<i>RA</i>	1.0	
Carbon disulfide	75-15-0					1.0E-01	<i>i</i>	2.0E-01	<i>i</i>	1.0E-01	0.1	<i>RA</i>	1.0	
Carbon tetrachloride	56-23-5	1.3E-01	<i>i</i>	5.3E-02	<i>i</i>	1.3E-01	7.0E-04	<i>i</i>	1.1E-02	<i>c</i>	7.0E-04	0.1	<i>RA</i>	1.0
Chlorobenzene	108-90-7					2.0E-02	<i>i</i>	1.7E-02	<i>n</i>	2.0E-02	0.1	<i>RA</i>	1.0	
Chloroethane	75-00-3	2.9E-03	<i>n</i>	2.9E-03	<i>r</i>	2.9E-03	4.0E-01	<i>n</i>	2.9E+00	<i>i</i>	4.0E-01	0.1	<i>RA</i>	1.0
Chloroform	67-66-3	3.1E-02	<i>c</i>	8.1E-02	<i>i</i>	3.1E-02	1.0E-02	<i>i</i>	1.4E-02	<i>n</i>	1.0E-02	0.1	<i>RA</i>	1.0
Chloromethane	74-87-3	1.3E-02	<i>t</i>	6.3E-03	<i>t</i>	1.3E-02	2.6E-02	<i>r</i>	2.6E-02	<i>i</i>	2.6E-02	0.1	<i>RA</i>	1.0
2-Chloronaphthalene	91-58-7					8.0E-02	<i>i</i>	8.0E-02	<i>r</i>	8.0E-02	0.1	<i>RA</i>	1.0	
2-Chlorophenol	95-57-8					5.0E-03	<i>i</i>	5.0E-03	<i>r</i>	5.0E-03	0.1	<i>RA</i>	1.0	
2-Chlorotoluene	95-49-8					2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0	
4-Chlorotoluene	106-43-4					2.0E-02	<i>t</i>	7.4E-05	<i>t</i>	2.0E-02	0.1	<i>RA</i>	1.0	
Dibromochloromethane	124-48-1	8.4E-02	<i>i</i>	9.5E-02	<i>c</i>	8.4E-02	2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0
1,2-Dichlorobenzene	95-50-1					9.0E-02	<i>i</i>	5.7E-02	<i>h</i>	9.0E-02	0.1	<i>RA</i>	1.0	
1,3-Dichlorobenzene	541-73-1					3.0E-02	<i>n</i>	3.0E-02	<i>r</i>	3.0E-02	0.1	<i>RA</i>	1.0	
1,4-Dichlorobenzene	106-46-7	5.4E-03	<i>c</i>	2.2E-02	<i>n</i>	5.4E-03	2.3E-01	<i>n</i>	2.3E-01	<i>i</i>	2.3E-01	0.1	<i>RA</i>	1.0
Dichlorodifluoromethane	75-71-8					2.0E-01	<i>i</i>	5.7E-02	<i>h</i>	2.0E-01	0.1	<i>RA</i>	1.0	
1,1-Dichloroethane	75-34-3	5.7E-03	<i>c</i>	5.6E-03	<i>c</i>	5.7E-03	1.0E-01	<i>h</i>	1.4E-02	<i>n</i>	1.0E-01	0.1	<i>RA</i>	1.0
1,1-Dichloroethylene	75-35-4					5.0E-02	<i>i</i>	5.7E-02	<i>i</i>	5.0E-02	0.1	<i>RA</i>	1.0	
cis-1,2-Dichloroethylene	156-59-2					1.0E-02	<i>p</i>	1.0E-02	<i>r</i>	1.0E-02	0.1	<i>RA</i>	1.0	
trans-1,2-Dichloroethylene	156-60-5					2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0	
1,2-Dichloropropane	78-87-5	3.6E-02	<i>c</i>	3.6E-02	<i>c</i>	3.6E-02	1.1E-03	<i>r</i>	1.1E-03	<i>i</i>	1.1E-03	0.1	<i>RA</i>	1.0
1,3-Dichloropropene	542-75-6	1.0E-01	<i>i</i>	1.4E-02	<i>i</i>	1.0E-01	3.0E-02	<i>i</i>	5.7E-03	<i>i</i>	3.0E-02	0.1	<i>RA</i>	1.0
Diisopropyl ether (DIPE)	108-20-3													
1,4-Dioxane	123-91-1	1.1E-02	<i>i</i>	2.7E-02	<i>c</i>	1.1E-02	8.6E-01	<i>r</i>	8.6E-01	<i>c</i>	8.6E-01	0.1	<i>RA</i>	1.0
Ethanol	64-17-5													
Ethylbenzene	100-41-4													

**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor				Reference Dose				Absorption Factor							
		Oral, SF <sub>o</sub>		Inhalation, SF <sub>i</sub>		Dermal, SF <sub>d</sub>		Oral, RfD <sub>o</sub>		Inhalation, RfD <sub>i</sub>		Dermal, RfD <sub>d</sub>		Dermal, RA <sub>d</sub>		Oral, RA <sub>o</sub>	
		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>		(mg/kg-day)		(mg/kg-day)		(mg/kg-day)		(unitless)		(unitless)	
Ethylene dibromide (EDB)	106-93-4																
Ethylene dichloride (EDC)	107-06-2																
Ethyl-tert-butyl-ether (ETBE)	637-92-3																
n-Hexane	110-54-3							1.1E+01	<i>p</i>	5.7E-02	<i>i</i>	1.1E+01	0.1	<i>RA</i>		1.0	
Isopropylbenzene (Cumene)	98-82-8							1.0E-01	<i>i</i>	1.1E-01	<i>i</i>	1.0E-01	0.1	<i>RA</i>		1.0	
4-Isopropyltoluene	99-87-6							3.0E-01	<i>i</i>	3.0E-01	<i>r</i>	3.0E-01	0.1	<i>RA</i>		1.0	
Methanol	67-56-1																
Methyl ethyl ketone	78-93-3							6.0E-01	<i>i</i>	1.4E+00	<i>i</i>	6.0E-01	0.1	<i>RA</i>		1.0	
Methyl iodide	74-88-4							1.4E-03	<i>t</i>	3.4E-03	<i>t</i>	1.4E-03	0.1	<i>RA</i>		1.0	
Methyl butyl ketone	591-78-6							6.0E-02	<i>t</i>	1.1E-03	<i>t</i>	6.0E-02	0.1	<i>RA</i>		1.0	
Methyl isobutyl ketone	108-10-1							8.0E-02	<i>h</i>	8.6E-01	<i>i</i>	8.0E-02	0.1	<i>RA</i>		1.0	
Methyl tertiary butyl ether (MTBE)	1634-04-4																
Methylene chloride	75-09-2	7.5E-03	<i>i</i>	1.6E-03	<i>i</i>	7.5E-03	6.0E-02	<i>i</i>	1.1E-01	<i>c</i>	6.0E-02	0.1	<i>RA</i>		1.0		
Nitrobenzene	98-95-3						5.0E-04	<i>i</i>	5.7E-04	<i>h</i>	5.0E-04	0.1	<i>RA</i>		1.0		
n-Propylbenzene	103-65-1						4.0E-02	<i>n</i>	4.0E-02	<i>r</i>	4.0E-02	0.1	<i>RA</i>		1.0		
Styrene	100-42-5						2.0E-01	<i>i</i>	2.9E-01	<i>i</i>	2.0E-01	0.1	<i>RA</i>		1.0		
1,1,1,2-Tetrachloroethane	630-20-6	2.6E-02	<i>i</i>	2.6E-02	<i>i</i>	2.6E-02	3.0E-02	<i>i</i>	3.0E-02	<i>r</i>	3.0E-02	0.1	<i>RA</i>		1.0		
1,1,2,2-Tetrachloroethane	79-34-5	2.0E-01	<i>i</i>	2.0E-01	<i>i</i>	2.0E-01	6.0E-02	<i>p</i>	6.0E-02	<i>r</i>	6.0E-02	0.1	<i>RA</i>		1.0		
1,2,4,5-Tetrachlorobenzene	95-94-3						3.0E-04	<i>i</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RA</i>		1.0		
Tetrachloroethylene	127-18-4	5.4E-01	<i>c</i>	2.1E-02	<i>c</i>	5.4E-01	1.0E-02	<i>i</i>	7.7E-02	<i>t</i>	1.0E-02	0.1	<i>RA</i>		1.0		
Tetrahydrofuran	109-99-9	7.6E-03	<i>n</i>	6.8E-03	<i>n</i>	7.6E-03	2.1E-01	<i>n</i>	8.6E-02	<i>n</i>	2.1E-01	0.1	<i>RA</i>		1.0		
Tertiary-amyl-methyl-ether (TAME)	994-05-8																
Tertiary-butyl-alcohol (TBA)	75-65-0																
Toluene	108-88-3																
1,2,4-Trichlorobenzene	120-82-1	3.6E-03	<i>c</i>	3.6E-03	<i>r</i>	3.6E-03	1.0E-02	<i>i</i>	1.0E-03	<i>p</i>	1.0E-02	0.1	<i>RA</i>		1.0		
1,3,5-Trichlorobenzene	108-70-3						3.0E-03	<i>t</i>	1.1E-02	<i>t</i>	3.0E-03	0.1	<i>RA</i>		1.0		
1,1,1-Trichloroethane	71-55-6						2.8E-01	<i>n</i>	6.3E-01	<i>p</i>	2.8E-01	0.1	<i>RA</i>		1.0		
1,1,2-Trichloroethane	79-00-5	5.7E-02	<i>i</i>	5.6E-02	<i>i</i>	5.7E-02	4.0E-03	<i>i</i>	4.0E-03	<i>r</i>	4.0E-03	0.1	<i>RA</i>		1.0		
Trichloroethylene	79-01-6	1.3E-02	<i>c</i>	7.0E-03	<i>c</i>	1.3E-02	1.7E-01	<i>r</i>	1.7E-01	<i>c</i>	1.7E-01	0.1	<i>RA</i>		1.0		
Trichlorofluoromethane	75-69-4						3.0E-01	<i>i</i>	2.0E-01	<i>h</i>	3.0E-01	0.1	<i>RA</i>		1.0		
1,2,3-Trichloropropane	96-18-4	2.0E+00	<i>n</i>	2.0E+00	<i>r</i>	2.0E+00	6.0E-03	<i>i</i>	1.4E-03	<i>n</i>	6.0E-03	0.1	<i>RA</i>		1.0		
1,1,2-Trichlorotrifluoroethane	76-13-1						3.0E+01	<i>i</i>	8.6E+00	<i>h</i>	3.0E+01	0.1	<i>RE</i>		1.0		
1,2,4-Trimethylbenzene	95-63-6						5.0E-02	<i>n</i>	1.7E-03	<i>p</i>	5.0E-02	0.1	<i>RA</i>		1.0		
1,3,5-Trimethylbenzene	108-67-8						5.0E-02	<i>n</i>	1.7E-03	<i>p</i>	5.0E-02	0.1	<i>RA</i>		1.0		
Vinyl chloride*	75-01-4	1.4E+00	<i>i</i>	3.1E-02	<i>i</i>	1.4E+00	3.0E-03	<i>i</i>	2.9E-02	<i>i</i>	3.0E-03	0.1	<i>RA</i>		1.0		
Xylenes (total)	1330-20-7																
SVOCs																	
Acenaphthene	83-32-9																
Acenaphthylene	208-96-8						6.0E-02	<i>t</i>	6.0E-02	<i>r</i>	6.0E-02	0.1	<i>RE</i>		1.0		
Acrylamide	79-06-1	4.5E+00	<i>i</i>	4.5E+00	<i>i</i>	4.5E+00	2.0E-04	<i>i</i>	2.0E-04	<i>r</i>	2.0E-04	0.1	<i>RE</i>		1.0		
Acrylic acid	79-10-7						5.0E-01	<i>i</i>	2.9E-04	<i>i</i>	5.0E-01	0.1	<i>RE</i>		1.0		

**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor					Reference Dose					Absorption Factor		
		Oral, SF <sub>o</sub>		Inhalation, SF <sub>i</sub>		Dermal, SF <sub>d</sub>	Oral, RfD <sub>o</sub>		Inhalation, RfD <sub>i</sub>		Dermal, RfD <sub>d</sub>	Dermal, RAF <sub>d</sub>		Oral, RAF <sub>o</sub>
		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>	(mg/kg-day)		(mg/kg-day)		(mg/kg-day)		(unitless)	(unitless)
Aniline	62-53-3	5.7E-03	<i>i</i>	5.7E-03	<i>c</i>	5.7E-03	7.0E-03	<i>p</i>	2.9E-04	<i>i</i>	7.0E-03	0.1	<i>RE</i>	1.0
Anthracene	120-12-7													
Aroclor 1016	12674-11-2	7.0E-02	<i>a</i>	7.0E-02	<i>a</i>	7.0E-02	7.0E-05	<i>i</i>	7.0E-05	<i>r</i>	7.0E-05	0.14	<i>RE</i>	1.0
Aroclor 1221	11104-28-2	2.0E+00	<i>a</i>	2.0E+00	<i>a</i>	2.0E+00	2.0E-05	<i>a</i>	2.0E-05	<i>a</i>	2.0E-05	0.14	<i>RE</i>	1.0
Aroclor 1242	53469-21-9	2.0E+00	<i>a</i>	2.0E+00	<i>a</i>	2.0E+00	2.0E-05	<i>a</i>	2.0E-05	<i>a</i>	2.0E-05	0.14	<i>RE</i>	1.0
Aroclor 1248	12672-29-6	2.0E+00	<i>a</i>	2.0E+00	<i>a</i>	2.0E+00	2.0E-05	<i>a</i>	2.0E-05	<i>a</i>	2.0E-05	0.14	<i>RE</i>	1.0
Aroclor 1254	11097-69-1	2.0E+00	<i>a</i>	2.0E+00	<i>a</i>	2.0E+00	2.0E-05	<i>i</i>	2.0E-05	<i>r</i>	2.0E-05	0.14	<i>RE</i>	1.0
Aroclor 1260	11096-82-5	2.0E+00	<i>a</i>	2.0E+00	<i>a</i>	2.0E+00	2.0E-05	<i>a</i>	2.0E-05	<i>a</i>	2.0E-05	0.14	<i>RE</i>	1.0
Azobenzene	103-33-3	1.1E-01	<i>i</i>	1.1E-01	<i>i</i>	1.1E-01						0.1	<i>RE</i>	1.0
Benzidine	92-87-5	2.3E+02	<i>i</i>	2.3E+02	<i>i</i>	2.3E+02	3.0E-03	<i>i</i>	3.0E-03	<i>r</i>	3.0E-03	0.1	<i>RA</i>	1.0
Benzo(a)anthracene	56-55-3													
Benzo(a)pyrene	50-32-8													
Benzo(b)fluoranthene	205-99-2													
Benzo(g,h,i)perylene	191-24-2						3.0E-02	<i>t</i>	3.0E-02	<i>r</i>	3.0E-02	0.13	<i>RE</i>	1.0
Benzo(k)fluoranthene	207-08-9													
Benzoic acid	65-85-0						4.0E+00	<i>i</i>	4.0E+00	<i>r</i>	4.0E+00	0.1	<i>RE</i>	1.0
Benzyl alcohol	100-51-6						3.0E-01	<i>h</i>	3.0E-01	<i>r</i>	3.0E-01	0.1	<i>RE</i>	1.0
Bis(2-chloroethyl) ether	111-44-4	1.1E+00	<i>i</i>	1.2E+00	<i>i</i>	1.1E+00						0.1	<i>RE</i>	1.0
Bis(2-chloroisopropyl)ether	108-60-1	7.0E-02	<i>t</i>	3.5E-02	<i>t</i>	7.0E-02	4.0E-02	<i>i</i>	4.0E-02	<i>r</i>	4.0E-02	0.1	<i>RE</i>	1.0
Bis(2-ethylhexyl)phthalate	117-81-7	1.4E-02	<i>i</i>	1.4E-02	<i>r</i>	1.4E-02	2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RE</i>	1.0
4-Bromophenyl phenyl ether	101-55-3	1.5E+01	<i>t</i>	1.2E+01	<i>t</i>	1.5E+01						0.1	<i>RE</i>	1.0
Butyl benzyl phthalate	85-68-7						2.0E-01	<i>i</i>	2.0E-01	<i>r</i>	2.0E-01	0.1	<i>RE</i>	1.0
Carbazole	86-74-8	2.0E-02	<i>h</i>	2.0E-02	<i>r</i>	2.0E-02						0.1	<i>RE</i>	1.0
p-Chloroaniline	106-47-8						4.0E-03	<i>i</i>	4.0E-03	<i>r</i>	4.0E-03	0.1	<i>RE</i>	1.0
4-Chlorophenyl phenyl ether	7005-72-3	1.5E+01	<i>t</i>	1.2E+01	<i>t</i>	1.5E+01						0.1	<i>RE</i>	1.0
Chrysene	218-01-9													
Dibenzo(a,h)anthracene	53-70-3													
Dibenzofuran	132-64-9						2.0E-03	<i>n</i>	2.0E-03	<i>r</i>	2.0E-03	0.03	<i>RE</i>	1.0
1,2-Dibromo-3-chloropropane	96-12-8	1.4E+00	<i>h</i>	1.4E+00	<i>r</i>	1.4E+00	5.7E-05	<i>r</i>	5.7E-05	<i>i</i>	5.7E-05	0.1	<i>RE</i>	1.0
Dibutyl phthalate	84-74-2						1.0E-01	<i>i</i>	1.0E-01	<i>r</i>	1.0E-01	0.1	<i>RE</i>	1.0
3,3-Dichlorobenzidine	91-94-1	4.5E-01	<i>i</i>	1.2E+00	<i>c</i>	4.5E-01						0.1	<i>RE</i>	1.0
2,4-Dichlorophenol	120-83-2						3.0E-03	<i>i</i>	3.0E-03	<i>r</i>	3.0E-03	0.1	<i>RE</i>	1.0
Diethyl phthalate	84-66-2						8.0E-01	<i>i</i>	8.0E-01	<i>r</i>	8.0E-01	0.1	<i>RE</i>	1.0
2,4-Dimethylphenol	105-67-9						2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RE</i>	1.0
2,6-Dimethylphenol	576-26-1						6.0E-04	<i>i</i>	6.0E-04	<i>r</i>	6.0E-04	0.1	<i>RE</i>	1.0
Dimethyl phthalate	131-11-3						1.0E+01	<i>h</i>	1.0E+01	<i>r</i>	1.0E+01	0.1	<i>RE</i>	1.0
1,3-Dinitrobenzene	99-65-0						1.0E-04	<i>i</i>	1.0E-04	<i>r</i>	1.0E-04	0.1	<i>RE</i>	1.0
2,4-Dinitrophenol	51-28-5						2.0E-03	<i>i</i>	2.0E-03	<i>r</i>	2.0E-03	0.1	<i>RE</i>	1.0
2,4-Dinitrotoluene	121-14-2	3.1E-01	<i>c</i>	3.1E-01	<i>c</i>	3.1E-01	2.0E-03	<i>i</i>	2.0E-03	<i>r</i>	2.0E-03	0.1	<i>RE</i>	1.0
2,6-Dinitrotoluene	606-20-2	6.8E-01	<i>i</i>	6.8E-01	<i>r</i>	6.8E-01	1.0E-03	<i>h</i>	1.0E-03	<i>r</i>	1.0E-03	0.1	<i>RE</i>	1.0
4-Amino-2,6-dinitrotoluene	19406-51-0	1.0E-02	<i>t</i>	1.0E-02	<i>r</i>	1.0E-02	1.7E-04	<i>t</i>	2.9E-05	<i>t</i>	1.7E-04	0.1	<i>RE</i>	1.0

**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor					Reference Dose					Absorption Factor		
		Oral, SF <sub>o</sub>		Inhalation, SF <sub>i</sub>		Dermal, SF <sub>d</sub>	Oral, RfD <sub>o</sub>		Inhalation, RfD <sub>i</sub>		Dermal, RfD <sub>d</sub>	Dermal, RAF <sub>d</sub>		Oral, RAF <sub>o</sub>
		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>	(mg/kg-day)		(mg/kg-day)		(mg/kg-day)		(unitless)	(unitless)
2-Amino-4,6-dinitrotoluene	35572-78-2	1.0E-02	<i>t</i>	1.0E-02	<i>r</i>	1.0E-02	1.7E-04	<i>t</i>	2.9E-05	<i>t</i>	1.7E-04	0.1	<i>RE</i>	1.0
Di(2-ethylhexyl)adipate	103-23-1	1.2E-03	<i>i</i>	1.2E-03	<i>r</i>	1.2E-03	6.0E-01	<i>i</i>	6.0E-01	<i>r</i>	6.0E-01	0.1	<i>RE</i>	1.0
Di-n-octylphthalate	117-84-0						4.0E-02	<i>p</i>	4.0E-02	<i>r</i>	4.0E-02	0.1	<i>RE</i>	1.0
1,2-Diphenylhydrazine	122-66-7	8.0E-01	<i>i</i>	7.7E-01	<i>i</i>	8.0E-01						0.1	<i>RE</i>	1.0
Diphenylamine	122-39-4						2.5E-02	<i>i</i>	2.9E-03	<i>t</i>	2.5E-02	0.1	<i>RE</i>	1.0
Ethylene glycol	107-21-1						2.0E+00	<i>i</i>	1.1E-01	<i>c</i>	2.0E+00	0.1	<i>RE</i>	1.0
Ethylene thiourea	96-45-7	4.5E-02	<i>c</i>	4.5E-02	<i>c</i>	4.5E-02	8.0E-05	<i>i</i>	8.0E-05	<i>r</i>	8.0E-05	0.1	<i>RE</i>	1.0
Fluoranthene	206-44-0													
Fluorene	86-73-7													
Formaldehyde	50-00-0	4.5E-02	<i>r</i>	4.5E-02	<i>i</i>	4.5E-02	2.0E-01	<i>i</i>	8.6E-04	<i>c</i>	2.0E-01	0.1	<i>RE</i>	1.0
Hexachlorobenzene	118-74-1	1.6E+00	<i>i</i>	1.6E+00	<i>i</i>	1.6E+00	8.0E-04	<i>i</i>	8.0E-04	<i>r</i>	8.0E-04	0.1	<i>RE</i>	1.0
Hexachlorobutadiene	87-68-3	7.8E-02	<i>i</i>	7.7E-02	<i>i</i>	7.8E-02	3.0E-04	<i>n</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RE</i>	1.0
Hexachlorocyclopentadiene	77-47-4						6.0E-03	<i>i</i>	5.7E-05	<i>i</i>	6.0E-03	0.1	<i>RE</i>	1.0
Hexachloroethane	67-72-1	1.4E-02	<i>i</i>	1.4E-02	<i>i</i>	1.4E-02	1.0E-03	<i>i</i>	1.0E-03	<i>r</i>	1.0E-03	0.1	<i>RE</i>	1.0
Hexachlorophene	70-30-4						3.0E-04	<i>i</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RE</i>	1.0
HMX	2691-41-0						5.0E-02	<i>i</i>	7.7E-04	<i>t</i>	5.0E-02	0.1	<i>RE</i>	1.0
Indeno(1,2,3-cd)pyrene	193-39-5	1.2E+00	<i>c</i>	3.9E-01	<i>c</i>	1.2E+00						0.13	<i>RE</i>	1.0
Isophorone	78-59-1	9.5E-04	<i>i</i>	9.5E-04	<i>r</i>	9.5E-04	2.0E-01	<i>i</i>	5.7E-01	<i>c</i>	2.0E-01	0.1	<i>RE</i>	1.0
Maleic anhydride	108-31-6						1.0E-01	<i>i</i>	2.0E-04	<i>c</i>	1.0E-01	0.1	<i>RE</i>	1.0
2-Methyl-4,6-dinitrophenol	534-52-1						1.0E-04	<i>p</i>	8.6E-05	<i>t</i>	1.0E-04	0.1	<i>RE</i>	1.0
2-Methylnaphthalene	91-57-6						4.0E-03	<i>i</i>	4.0E-03	<i>r</i>	4.0E-03	0.1	<i>RE</i>	1.0
2-Methylphenol	95-48-7						5.0E-02	<i>i</i>	5.0E-02	<i>r</i>	5.0E-02	0.1	<i>RE</i>	1.0
3-Methylphenol	108-39-4						5.0E-02	<i>i</i>	5.0E-02	<i>r</i>	5.0E-02	0.1	<i>RE</i>	1.0
4-Methylphenol	106-44-5						5.0E-03	<i>h</i>	5.0E-03	<i>r</i>	5.0E-03	0.1	<i>RE</i>	1.0
Methyl-2,4,6-trinitrophenylnitramine	479-45-8						1.0E-02	<i>t</i>	2.9E-05	<i>t</i>	1.0E-02	0.1	<i>RE</i>	1.0
m-Phenylenediamine	108-45-2						6.0E-03	<i>i</i>	6.0E-03	<i>r</i>	6.0E-03	0.1	<i>RE</i>	1.0
Naphthalene	91-20-3													
2-Nitroaniline	88-74-4						3.0E-03	<i>p</i>	3.0E-05	<i>p</i>	3.0E-03	0.1	<i>RE</i>	1.0
3-Nitroaniline	99-09-2	2.1E-02	<i>p</i>	2.1E-02	<i>r</i>	2.1E-02	3.0E-04	<i>p</i>	3.0E-04	<i>p</i>	3.0E-04	0.1	<i>RE</i>	1.0
4-Nitroaniline	100-01-6	2.1E-02	<i>p</i>	2.1E-02	<i>r</i>	2.1E-02	3.0E-03	<i>p</i>	1.0E-03	<i>p</i>	3.0E-03	0.1	<i>RE</i>	1.0
Nitroglycerin	55-63-0	1.4E-02	<i>n</i>	1.4E-02	<i>r</i>	1.4E-02	7.0E-05	<i>t</i>	7.0E-05	<i>r</i>	7.0E-05	0.1	<i>RE</i>	1.0
2-Nitrophenol	88-75-5						2.0E-03	<i>t</i>	1.1E-03	<i>t</i>	2.0E-03	0.1	<i>RE</i>	1.0
4-Nitrophenol	100-02-7						2.0E-03	<i>t</i>	2.9E-04	<i>t</i>	2.0E-03	0.1	<i>RE</i>	1.0
2-Nitrotoluene	88-72-2	2.3E-01	<i>p</i>	2.3E-01	<i>r</i>	2.3E-01	1.0E-02	<i>t</i>	3.1E-03	<i>t</i>	1.0E-02	0.1	<i>RE</i>	1.0
3-Nitrotoluene	99-08-1						2.0E-02	<i>p</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RE</i>	1.0
4-Nitrotoluene	99-99-0	1.7E-02	<i>p</i>	1.7E-02	<i>r</i>	1.7E-02	1.0E-02	<i>p</i>	1.0E-02	<i>r</i>	1.0E-02	0.1	<i>RE</i>	1.0
n-Nitrosodimethylamine	62-75-9	5.1E+01	<i>i</i>	4.9E+01	<i>i</i>	5.1E+01	8.0E-06	<i>p</i>	8.0E-06	<i>r</i>	8.0E-06	0.1	<i>RE</i>	1.0
n-Nitrosodi-n-propylamine	621-64-7	7.0E+00	<i>i</i>	7.0E+00	<i>c</i>	7.0E+00						0.1	<i>RE</i>	1.0
n-Nitrosodiphenylamine	86-30-6	4.9E-03	<i>i</i>	9.0E-03	<i>c</i>	4.9E-03	2.0E-02	<i>p</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RE</i>	1.0
n-Nitrosopyrrolidine*	930-55-2	2.1E+00	<i>i</i>	2.1E+00	<i>i</i>	2.1E+00						0.1	<i>RE</i>	1.0
Pentachlorobenzene	608-93-5						8.0E-04	<i>i</i>	8.0E-04	<i>r</i>	8.0E-04	0.1	<i>RE</i>	1.0



**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor			Reference Dose			Absorption Factor		
		Oral, SF <sub>o</sub> (mg/kg-day) <sup>-1</sup>	Inhalation, SF <sub>i</sub> (mg/kg-day) <sup>-1</sup>	Dermal, SF <sub>d</sub> (mg/kg-day) <sup>-1</sup>	Oral, RfD <sub>o</sub> (mg/kg-day)	Inhalation, RfD <sub>i</sub> (mg/kg-day)	Dermal, RfD <sub>d</sub> (mg/kg-day)	Dermal, RAF <sub>d</sub> (unitless)	Oral, RAF <sub>o</sub> (unitless)	
Pentachloronitrobenzene	82-68-8	2.6E-01 <i>h</i>	2.6E-01 <i>r</i>	2.6E-01	3.0E-03 <i>i</i>	3.0E-03 <i>r</i>	3.0E-03	0.1 <i>RE</i>	1.0	
Pentachlorophenol	87-86-5	1.2E-01 <i>i</i>	1.8E-02 <i>c</i>	1.2E-01	3.0E-02 <i>i</i>	3.0E-02 <i>r</i>	3.0E-02	0.25 <i>RE</i>	1.0	
Pentaerythritol tetranitrate	78-11-5				4.0E-01 <i>t</i>	4.0E-01 <i>r</i>	4.0E-01	0.1 <i>RE</i>	1.0	
Phenanthrene	85-01-8				3.0E-02 <i>t</i>	3.0E-02 <i>r</i>	3.0E-02	0.1 <i>RE</i>	1.0	
Phenol	108-95-2				3.0E-01 <i>i</i>	5.7E-02 <i>c</i>	3.0E-01	0.1 <i>RE</i>	1.0	
Polychlorinated biphenyls (PCBs)	1336-36-3	2.0E+00 <i>i</i>	3.5E-01 <i>i</i>	2.0E+00				0.14 <i>RE</i>	1.0	
Pyrene	129-00-0									
RDX	121-82-4	1.1E-01 <i>i</i>	1.1E-01 <i>r</i>	1.1E-01	3.0E-03 <i>i</i>	3.0E-03 <i>r</i>	3.0E-03	0.1 <i>RE</i>	1.0	
2,4,5-Trichlorophenol	95-95-4				1.0E-01 <i>i</i>	1.0E-01 <i>r</i>	1.0E-01	0.1 <i>RE</i>	1.0	
2,4,6-Trichlorophenol	88-06-2	1.1E-02 <i>i</i>	1.1E-02 <i>i</i>	1.1E-02	1.0E-04 <i>n</i>	1.0E-04 <i>r</i>	1.0E-04	0.1 <i>RE</i>	1.0	
1,3,5-Trinitrobenzene	99-35-4				3.0E-02 <i>i</i>	3.0E-02 <i>r</i>	3.0E-02	0.1 <i>RE</i>	1.0	
2,4,6-Trinitrotoluene (TNT)	118-96-7	3.0E-02 <i>i</i>	3.0E-02 <i>r</i>	3.0E-02	5.0E-04 <i>i</i>	5.0E-04 <i>r</i>	5.0E-04	0.1 <i>RE</i>	1.0	
<b>Pesticides</b>										
Acetochlor	34256-82-1				2.0E-02 <i>i</i>	2.0E-02 <i>r</i>	2.0E-02	0.1 <i>RA</i>	1.0	
Acifluorfen	62476-59-9				1.3E-02 <i>i</i>	2.9E-03 <i>t</i>	1.3E-02	0.1 <i>RA</i>	1.0	
Acrolein	107-02-8				5.0E-04 <i>i</i>	5.7E-06 <i>i</i>	5.0E-04	0.1 <i>RA</i>	1.0	
Alachlor	15972-60-8	5.6E-02 <i>c</i>	8.0E-02 <i>r</i>	5.6E-02	1.0E-02 <i>i</i>	1.0E-02 <i>r</i>	1.0E-02	0.1 <i>RA</i>	1.0	
Aldicarb	116-06-3				1.0E-03 <i>i</i>	1.0E-03 <i>r</i>	1.0E-03	0.1 <i>RA</i>	1.0	
Aldicarb sulfone	1646-88-4				1.0E-03 <i>i</i>	1.0E-03 <i>r</i>	1.0E-03	0.1 <i>RA</i>	1.0	
Aldrin	309-00-2	1.7E+01 <i>i</i>	1.7E+01 <i>i</i>	1.7E+01	3.0E-05 <i>i</i>	3.0E-05 <i>r</i>	3.0E-05	0.1 <i>RA</i>	1.0	
alpha-Hexachlorocyclohexane	319-84-6	6.3E+00 <i>i</i>	6.3E+00 <i>i</i>	6.3E+00	5.0E-04 <i>n</i>	5.0E-04 <i>r</i>	5.0E-04	0.1 <i>RA</i>	1.0	
Ametryn	834-12-8				9.0E-03 <i>i</i>	9.0E-03 <i>r</i>	9.0E-03	0.1 <i>RA</i>	1.0	
Atrazine	1912-24-9	2.3E-01 <i>c</i>	2.2E-01 <i>r</i>	2.3E-01	3.5E-02 <i>i</i>	3.5E-02 <i>r</i>	3.5E-02	0.1 <i>RA</i>	1.0	
Baygon	114-26-1				4.0E-03 <i>i</i>	4.0E-03 <i>r</i>	4.0E-03	0.1 <i>RA</i>	1.0	
Butylate	2008-41-5				5.0E-02 <i>i</i>	5.0E-02 <i>r</i>	5.0E-02	0.1 <i>RA</i>	1.0	
beta-Hexachlorocyclohexane	319-85-7	1.8E+00 <i>i</i>	1.8E+00 <i>i</i>	1.8E+00	2.0E-04 <i>n</i>	2.0E-04 <i>r</i>	2.0E-04	0.1 <i>RA</i>	1.0	
4-(2,4-Dichlorophenoxy) butyric acid (2,4-DB)	94-82-6				8.0E-03 <i>i</i>	8.0E-03 <i>r</i>	8.0E-03	0.04 <i>RE</i>	1.0	
Captan	133-06-2	2.3E-03 <i>c</i>	2.3E-03 <i>c</i>	2.3E-03	1.3E-01 <i>i</i>	1.3E-01 <i>r</i>	1.3E-01	0.1 <i>RA</i>	1.0	
Carbaryl	63-25-2				1.0E-01 <i>i</i>	1.1E-01 <i>r</i>	1.0E-01	0.1 <i>RA</i>	1.0	
Carbofuran	1563-66-2				5.0E-03 <i>i</i>	5.0E-03 <i>r</i>	5.0E-03	0.1 <i>RA</i>	1.0	
Carboxin	5234-68-4				1.0E-01 <i>i</i>	1.0E-01 <i>r</i>	1.0E-01	0.1 <i>RA</i>	1.0	
Chloramben	133-90-4				1.5E-02 <i>i</i>	1.5E-02 <i>r</i>	1.5E-02	0.1 <i>RA</i>	1.0	
Chlordane (technical)	12789-03-6	3.5E-01 <i>i</i>	3.5E-01 <i>i</i>	3.5E-01	5.0E-04 <i>i</i>	2.0E-04 <i>i</i>	5.0E-04	0.1 <i>RA</i>	1.0	
Chlordane, gamma	57-74-9	3.5E-01 <i>t</i>	3.5E-01 <i>t</i>	3.5E-01	5.0E-04 <i>t</i>	2.0E-04 <i>t</i>	5.0E-04	0.04 <i>RE</i>	1.0	
Chlorothalonil	1897-45-6	3.1E-03 <i>c</i>	3.1E-03 <i>c</i>	3.1E-03	1.5E-02 <i>i</i>	1.5E-02 <i>r</i>	1.5E-02	0.04 <i>RE</i>	1.0	
Chlorpyrifos	2921-88-2				3.0E-03 <i>i</i>	3.0E-03 <i>r</i>	3.0E-03	0.1 <i>RA</i>	1.0	
Coumaphos	56-72-4				7.0E-03 <i>t</i>	7.0E-03 <i>r</i>	7.0E-03	0.1 <i>RA</i>	1.0	
Cyanazine	21725-46-2	8.4E-01 <i>h</i>	8.4E-01 <i>r</i>	8.4E-01	2.0E-03 <i>h</i>	2.0E-03 <i>r</i>	2.0E-03	0.1 <i>RA</i>	1.0	
Dacthal	1861-32-1				1.0E-02 <i>i</i>	1.0E-02 <i>r</i>	1.0E-02	0.1 <i>RA</i>	1.0	
Dalapon, sodium salt	75-99-0				3.0E-02 <i>i</i>	3.0E-02 <i>r</i>	3.0E-02	0.1 <i>RA</i>	1.0	
DDD	72-54-8	2.4E-01 <i>i</i>	2.4E-01 <i>c</i>	2.4E-01				0.1 <i>RA</i>	1.0	
DDE	72-55-9	3.4E-01 <i>i</i>	3.4E-01 <i>c</i>	3.4E-01				0.1 <i>RA</i>	1.0	

**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor					Reference Dose					Absorption Factor		
		Oral, SF <sub>o</sub>		Inhalation, SF <sub>i</sub>		Dermal, SF <sub>d</sub>	Oral, RfD <sub>o</sub>		Inhalation, RfD <sub>i</sub>		Dermal, RfD <sub>d</sub>	Dermal, RAF <sub>d</sub>		Oral, RAF <sub>o</sub>
		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>		(mg/kg-day) <sup>-1</sup>	(mg/kg-day)		(mg/kg-day)		(mg/kg-day)	(unitless)		(unitless)
DDT	50-29-3	3.4E-01	<i>i</i>	3.4E-01	<i>i</i>	3.4E-01	5.0E-04	<i>i</i>	5.0E-04	<i>r</i>	5.0E-04	0.1	<i>RA</i>	1.0
DEF	78-48-8						3.0E-05	<i>i</i>	3.0E-05	<i>r</i>	3.0E-05	0.03	<i>RE</i>	1.0
delta-Hexachlorocyclohexane	319-86-8	1.8E+00	<i>t</i>	1.8E+00	<i>t</i>	1.8E+00	3.0E-04	<i>t</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RA</i>	1.0
Demeton	8065-48-3						4.0E-04	<i>i</i>	4.0E-05	<i>r</i>	4.0E-04	0.1	<i>RA</i>	1.0
Diazinon	333-41-5						9.0E-04	<i>h</i>	9.0E-04	<i>r</i>	9.0E-04	0.1	<i>RA</i>	1.0
Dicamba	1918-00-9						3.0E-02	<i>i</i>	3.0E-02	<i>r</i>	3.0E-02	0.1	<i>RA</i>	1.0
2,4-Dichlorophenoxy acetic acid (2,4-D)	94-75-7						1.0E-02	<i>i</i>	1.0E-02	<i>r</i>	1.0E-02	0.1	<i>RA</i>	1.0
Dichloroprop (2,4-DP)	120-36-5						1.0E-02	<i>t</i>	1.0E-02	<i>r</i>	1.0E-02	0.05	<i>RE</i>	1.0
Dieldrin	60-57-1	1.6E+01	<i>i</i>	1.6E+01	<i>i</i>	1.6E+01	5.0E-05	<i>i</i>	5.0E-05	<i>r</i>	5.0E-05	0.1	<i>RA</i>	1.0
Dimethoate	60-51-5						2.0E-04	<i>i</i>	2.0E-04	<i>r</i>	2.0E-04	0.1	<i>RA</i>	1.0
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	88-85-7						1.0E-03	<i>i</i>	1.0E-03	<i>r</i>	1.0E-03	0.1	<i>RA</i>	1.0
Diquat	85-00-7						2.2E-03	<i>i</i>	2.2E-03	<i>r</i>	2.2E-03	0.1	<i>RA</i>	1.0
Disulfoton	298-04-4						4.0E-05	<i>i</i>	4.0E-05	<i>r</i>	4.0E-05	0.1	<i>RA</i>	1.0
Diuron	330-54-1						2.0E-03	<i>i</i>	2.0E-03	<i>r</i>	2.0E-03	0.1	<i>RA</i>	1.0
Endosulfan	115-29-7						6.0E-03	<i>i</i>	6.0E-03	<i>r</i>	6.0E-03	0.1	<i>RA</i>	1.0
Endothall	145-73-3						2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0
Endrin	72-20-8						3.0E-04	<i>i</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RA</i>	1.0
Endrin aldehyde	7421-93-4						3.0E-04	<i>t</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RA</i>	1.0
Endrin Ketone	53494-70-5						3.0E-04	<i>t</i>	2.9E-05	<i>t</i>	3.0E-04	0.1	<i>RA</i>	1.0
Eptam	759-94-4						2.5E-02	<i>i</i>	2.5E-02	<i>r</i>	2.5E-02	0.1	<i>RA</i>	1.0
Ethoprop	13194-48-4	2.8E-02	<i>t</i>	2.8E-02	<i>r</i>	2.8E-02	1.0E-04	<i>t</i>	1.0E-04	<i>r</i>	1.0E-04	0.1	<i>RA</i>	1.0
Fenamiphos	22224-92-6						2.5E-04	<i>i</i>	2.5E-04	<i>r</i>	2.5E-04	0.1	<i>RA</i>	1.0
Fenthion	55-38-9						7.0E-05	<i>t</i>	7.0E-05	<i>r</i>	7.0E-05	0.1	<i>RA</i>	1.0
Fluometuron	2164-17-2						1.3E-02	<i>i</i>	1.3E-02	<i>r</i>	1.3E-02	0.1	<i>RA</i>	1.0
Fonofos	944-22-9						2.0E-03	<i>i</i>	2.0E-03	<i>r</i>	2.0E-03	0.1	<i>RA</i>	1.0
gamma-Hexachlorocyclohexane	58-89-9	1.1E+00	<i>c</i>	1.1E+00	<i>c</i>	1.1E+00	3.0E-04	<i>i</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RA</i>	1.0
Glyphosate	1071-83-6						1.0E-01	<i>i</i>	1.0E-01	<i>r</i>	1.0E-01	0.1	<i>RA</i>	1.0
Guthion	86-50-0						1.5E-03	<i>t</i>	1.5E-03	<i>r</i>	1.5E-03	0.1	<i>RA</i>	1.0
Heptachlor	76-44-8	4.5E+00	<i>i</i>	4.5E+00	<i>i</i>	4.5E+00	5.0E-04	<i>i</i>	5.0E-04	<i>r</i>	5.0E-04	0.1	<i>RA</i>	1.0
Heptachlor epoxide	1024-57-3	9.1E+00	<i>i</i>	9.1E+00	<i>i</i>	9.1E+00	1.3E-05	<i>i</i>	1.3E-05	<i>r</i>	1.3E-05	0.1	<i>RA</i>	1.0
Hexazinone	51235-04-2						3.3E-02	<i>i</i>	3.3E-02	<i>r</i>	3.3E-02	0.1	<i>RA</i>	1.0
Malathion	121-75-5						2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0
Maleic hydrazide	123-33-1						5.0E-01	<i>i</i>	5.0E-01	<i>r</i>	5.0E-01	0.1	<i>RA</i>	1.0
Maneb	12427-38-2						5.0E-03	<i>i</i>	5.0E-03	<i>r</i>	5.0E-03	0.1	<i>RA</i>	1.0
Methomyl	16752-77-5						2.5E-02	<i>i</i>	2.5E-02	<i>r</i>	2.5E-02	0.1	<i>RA</i>	1.0
Methoxychlor	72-43-5						5.0E-03	<i>i</i>	5.0E-03	<i>r</i>	5.0E-03	0.1	<i>RA</i>	1.0
2-Methyl-4-chlorophenoxyacetic acid (MCPA)	94-74-6						5.0E-04	<i>i</i>	5.0E-04	<i>r</i>	5.0E-04	0.1	<i>RA</i>	1.0
MCPP	93-65-2						1.0E-03	<i>i</i>	1.0E-03	<i>r</i>	1.0E-03	0.1	<i>RA</i>	1.0
Metolachlor	51218-45-2						1.5E-01	<i>i</i>	1.5E-01	<i>r</i>	1.5E-01	0.1	<i>RA</i>	1.0
Metribuzin	21087-64-9						2.5E-02	<i>i</i>	2.5E-02	<i>r</i>	2.5E-02	0.1	<i>RA</i>	1.0
Mirex	2385-85-5	1.8E+01	<i>c</i>	1.8E+01	<i>c</i>	1.8E+01	2.0E-04	<i>i</i>	2.0E-04	<i>r</i>	2.0E-04	0.1	<i>RA</i>	1.0
Naled	300-76-5						2.0E-03	<i>i</i>	2.0E-03	<i>r</i>	2.0E-03	0.1	<i>RA</i>	1.0

**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor				Reference Dose				Absorption Factor				
		Oral, SF <sub>o</sub> (mg/kg-day) <sup>-1</sup>	Inhalation, SF <sub>i</sub> (mg/kg-day) <sup>-1</sup>	Dermal, SF <sub>d</sub> (mg/kg-day) <sup>-1</sup>	Oral, RfD <sub>o</sub> (mg/kg-day)	Inhalation, RfD <sub>i</sub> (mg/kg-day)	Dermal, RfD <sub>d</sub> (mg/kg-day)	Dermal, RA <sub>d</sub> (unitless)	Oral, RA <sub>o</sub> (unitless)					
o,o,o-Triethylphosphorothioate	126-68-1				8.3E-06	<i>t</i>	8.3E-06	<i>r</i>	8.3E-06	0.1	<i>RA</i>	1.0		
Oxamyl	23135-22-0				2.5E-02	<i>i</i>	2.5E-02	<i>r</i>	2.5E-02	0.1	<i>RA</i>	1.0		
Paraquat	4685-14-7				4.5E-03	<i>i</i>	4.5E-03	<i>r</i>	4.5E-03	0.1	<i>RA</i>	1.0		
ethyl-Parathion	56-38-2				6.0E-03	<i>h</i>	6.0E-03	<i>r</i>	6.0E-03	0.1	<i>RA</i>	1.0		
methyl-Parathion	298-00-0				2.5E-04	<i>i</i>	2.5E-04	<i>r</i>	2.5E-04	0.1	<i>RA</i>	1.0		
Pendimethalin	40487-42-1				4.0E-02	<i>i</i>	4.0E-02	<i>r</i>	4.0E-02	0.1	<i>RA</i>	1.0		
Phenylmercuric acetate	62-38-4				8.0E-05	<i>i</i>	8.0E-05	<i>r</i>	8.0E-05	0.1	<i>RA</i>	1.0		
Phorate	298-02-2				2.0E-04	<i>h</i>	2.0E-04	<i>r</i>	2.0E-04	0.1	<i>RA</i>	1.0		
Picloram	1918-02-1				7.0E-02	<i>i</i>	7.0E-02	<i>r</i>	7.0E-02	0.1	<i>RA</i>	1.0		
Prometon	1610-18-0				1.5E-02	<i>i</i>	1.5E-02	<i>r</i>	1.5E-02	0.1	<i>RA</i>	1.0		
Pronamide	23950-58-5				7.5E-02	<i>i</i>	7.5E-02	<i>r</i>	7.5E-02	0.1	<i>RA</i>	1.0		
Propachlor	1918-16-7				1.3E-02	<i>i</i>	1.3E-02	<i>r</i>	1.3E-02	0.1	<i>RA</i>	1.0		
Propanil	709-98-8				5.0E-03	<i>i</i>	5.0E-03	<i>r</i>	5.0E-03	0.1	<i>RA</i>	1.0		
Propazine	139-40-2	4.5E-02	<i>t</i>	4.5E-02	<i>r</i>	4.5E-02	2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0
Propham	122-42-9				2.0E-02	<i>i</i>	2.0E-02	<i>r</i>	2.0E-02	0.1	<i>RA</i>	1.0		
Silvex (2,4,5-TP)	93-72-1				8.0E-03	<i>i</i>	8.0E-03	<i>r</i>	8.0E-03	0.1	<i>RA</i>	1.0		
Simazine	122-34-9	1.2E-01	<i>h</i>	1.2E-01	<i>r</i>	1.2E-01	5.0E-03	<i>i</i>	2.0E-03	<i>r</i>	5.0E-03	0.1	<i>RA</i>	1.0
Strychnine	57-24-9				3.0E-04	<i>i</i>	3.0E-04	<i>r</i>	3.0E-04	0.1	<i>RA</i>	1.0		
Tebuthiuron	34014-18-1				7.0E-02	<i>i</i>	7.0E-02	<i>r</i>	7.0E-02	0.1	<i>RA</i>	1.0		
Terbacil	5902-51-2				1.3E-02	<i>i</i>	1.3E-02	<i>r</i>	1.3E-02	0.1	<i>RA</i>	1.0		
Terbufos	13071-79-9				2.5E-05	<i>h</i>	2.5E-05	<i>r</i>	2.5E-05	0.1	<i>RA</i>	1.0		
Terbutryn	886-50-0				1.0E-03	<i>i</i>	1.0E-03	<i>r</i>	1.0E-03	0.1	<i>RA</i>	1.0		
Toxaphene	8001-35-2	1.1E+00	<i>i</i>	1.1E+00	<i>i</i>	1.1E+00				0.1	<i>RA</i>	1.0		
Triallate	2303-17-5				1.3E-02	<i>i</i>	1.3E-02	<i>r</i>	1.3E-02	0.1	<i>RA</i>	1.0		
2,4,5-Trichlorophenoxy acetic acid (2,4,5-T)	93-76-5				1.0E-02	<i>i</i>	1.0E-02	<i>r</i>	1.0E-02	0.1	<i>RA</i>	1.0		
Trifluralin	1582-09-8	7.7E-03	<i>i</i>	7.7E-03	<i>r</i>	7.7E-03	7.5E-03	<i>i</i>	7.5E-03	<i>r</i>	7.5E-03	0.1	<i>RA</i>	1.0
Warfarin	81-81-2				3.0E-04	<i>i</i>	2.9E-05	<i>t</i>	3.0E-04	0.1	<i>RA</i>	1.0		
Metals														
Aluminum	7429-90-5				1.0E+00	<i>p</i>	1.4E-03	<i>p</i>	1.0E+00	0.01	<i>RA</i>	1.0		
Antimony	7440-36-0				4.0E-04	<i>i</i>	1.4E-05	<i>t</i>	4.0E-04	0.01	<i>RA</i>	1.0		
Arsenic	7440-38-2													
Barium	7440-39-3													
Beryllium	7440-41-7	8.4E+00	<i>r</i>	8.4E+00	<i>i</i>	8.4E+00	2.0E-03	<i>i</i>	5.7E-06	<i>i</i>	2.0E-03	0.01	<i>RA</i>	1.0
Cadmium	7440-43-9													
Chromium (III) total chromium	7440-47-3													
Chromium (VI)	18540-29-9													
Copper	7440-50-8				4.0E-02	<i>h</i>	2.9E-04	<i>t</i>	4.0E-02	0.01	<i>RA</i>	1.0		
Lead	7439-92-1													
Manganese	7439-96-5				1.4E-01	<i>i</i>	1.4E-05	<i>i</i>	1.4E-01	0.01	<i>RA</i>	1.0		
Mercury	7439-97-6						8.6E-05	<i>i</i>		0.01	<i>RA</i>	1.0		
Molybdenum	7439-98-7				5.0E-03	<i>i</i>	1.4E-03	<i>t</i>	5.0E-03	0.01	<i>RA</i>	1.0		
Nickel	7440-02-0		9.1E-01	<i>c</i>	2.0E-02	<i>i</i>	2.6E-05	<i>t</i>	2.0E-02	0.01	<i>RA</i>	1.0		

**Table E-1**  
**Toxicity Values of Chemicals**

Chemicals	CAS #	Slope Factor			Reference Dose			Absorption Factor				
		Oral, SF <sub>o</sub>	Inhalation, SF <sub>i</sub>	Dermal, SF <sub>d</sub>	Oral, RfD <sub>o</sub>	Inhalation, RfD <sub>i</sub>	Dermal, RfD <sub>d</sub>	Dermal, RAF <sub>d</sub>	Oral, RAF <sub>o</sub>			
		(mg/kg-day) <sup>-1</sup>	(mg/kg-day) <sup>-1</sup>	(mg/kg-day) <sup>-1</sup>	(mg/kg-day)	(mg/kg-day)	(mg/kg-day)	(unitless)	(unitless)			
Selenium	7782-49-2											
Silver	7440-22-4				5.0E-03	<i>i</i>	2.9E-06	<i>t</i>	5.0E-03	0.01	<i>RA</i>	1.0
Strontium	7440-24-6				6.0E-01	<i>i</i>			6.0E-01	0.01	<i>RA</i>	1.0
Thallium chloride	7791-12-0				8.0E-05	<i>i</i>	2.9E-05	<i>t</i>	8.0E-05	0.01	<i>RA</i>	1.0
Vanadium	7440-62-2				7.0E-03	<i>h</i>	1.4E-05	<i>t</i>	7.0E-03	0.01	<i>RA</i>	1.0
Zinc	7440-66-6				3.0E-01	<i>i</i>			3.0E-01	0.01	<i>RA</i>	1.0
Inorganics												
Ammonia	7664-41-7						2.9E-02	<i>i</i>		0.1	<i>RA</i>	1.0
Cyanide	57-12-5				2.0E-02	<i>i</i>	1.4E-03	<i>t</i>	2.0E-02	0.1	<i>RA</i>	1.0
Cyanide (as Sodium Cyanide)	143-33-9				4.0E-02	<i>i</i>			4.0E-02	0.1	<i>RA</i>	1.0
Cyanogen bromide	506-68-3				9.0E-02	<i>i</i>	9.0E-02	<i>r</i>	9.0E-02	0.1	<i>RA</i>	1.0
Fluoride (as Sodium Fluoride)	7681-49-4									0.1	<i>RA</i>	1.0
Perchlorate	14797-73-0				7.0E-04	<i>i</i>	7.0E-04	<i>r</i>	7.0E-04	0.1	<i>RA</i>	1.0
White phosphorus	7723-14-0				2.0E-05	<i>i</i>	2.9E-05	<i>t</i>	2.0E-05	0.1	<i>RA</i>	1.0
Petroleum Hydrocarbons												
TPH-GR0												
Aliphatics - > C6-C8	NA											
Aliphatics - > C8-C10	NA											
Aromatics - >C8-C10	NA											
TPH-DR0												
Aliphatics - >C10-C12	NA											
Aliphatics - >C12-C16	NA											
Aliphatics - >C16-C21	NA											
Aromatics - >C10-C12	NA											
Aromatics - >C12-C16	NA											
Aromatics - >C16-C21	NA											
TPH-ORO												
Aliphatics - >C21-C35	NA											
Aromatics - >C21-C35	NA											

The letters in the table represent following sources:

- i - USEPA IRIS
- p - USEPA PPRTV's
- n - USEPA NCEA
- c - CALEPA OEHHA
- t - TCEQ's TRRP Tier 1 PCL Table
- h - HEAST
- r - Missing value; value showing is identical to a value available for another route of exposure
- m - MDNR/DHSS Memo, August 12, 2004
- u - Value kept from MDNR Tanks-RBCA Guidance
- a - Values assigned based on the most conservative Aroclor values found in the tiered hierarchy
- e - Estimated by RAGS Part E
- RA - RAGS Part A
- RE - RAGS Part E

Colors:

Yellow - Some or all toxicity values identified
Orange - Lead is evaluated seperately using IEUBK model
White - Chemicals in MRBCA Tanks guidance

\* (Vinyl chloride): For non-residential scenario use SFo of 0.72 mg/kg/day and a Unit Risk of 0.0044 mg/m

**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, K <sub>p</sub>	Relative Contribution of Permeability Coefficient, B		Lag Time, τ <sub>event</sub>		Duration of Event, t*		Fraction Absorbed Water, F <sub>A</sub>		
		(cm/hr)		(unitless)		(hr/event)		(hr)		(unitless)	
VOCs											
Acetone	67-64-1	5.23E-04	e	0.002	e	0.222	e	0.534	e	1.000	e
Acetonitrile	75-05-8	5.57E-04	e	0.001	e	0.179	e	0.428	e	1.000	e
Acrylonitrile	107-13-1	1.20E-03	RE	0.003	RE	0.211	RE	0.507	RE	1.000	RE
Allyl alcohol	107-18-6	9.70E-04	e	0.003	e	0.222	e	0.534	e	1.000	e
Allyl chloride	107-05-1	5.40E-03	RE	0.018	RE	0.286	RE	0.686	RE	1.000	RE
Benzene	71-43-2										
1,1-Biphenyl	92-52-4	6.54E-02	e	0.313	e	0.768	e	1.843	e	0.990	e
Bis(chloromethyl)ether	542-88-1	8.62E-04	e	0.004	e	0.463	e	1.111	e	1.000	e
Bromochloromethane	74-97-5	2.22E-03	e	0.010	e	0.558	e	1.339	e	1.000	e
Bromodichloromethane	75-27-4	4.60E-03	RE	0.023	RE	0.883	RE	2.120	RE	1.000	RE
Bromoform	75-25-2	2.20E-03	RE	0.014	RE	2.790	RE	6.696	RE	1.000	RE
Bromomethane	74-83-9	2.80E-03	RE	0.011	RE	0.363	RE	0.871	RE	1.000	RE
n-Butylbenzene	104-51-8	2.01E-01	e	0.882	e	0.562	e	2.161	e	1.000	e
sec-Butylbenzene	135-98-8	1.48E-01	e	0.651	e	0.562	e	2.213	e	1.000	e
tert-Butylbenzene	98-06-6	1.70E-01	e	0.746	e	0.562	e	2.170	e	1.000	e
Carbon disulfide	75-15-0	1.70E-02	RE	0.059	RE	0.299	RE	0.718	RE	1.000	RE
Carbon tetrachloride	56-23-5	1.60E-02	RE	0.078	RE	0.776	RE	1.863	RE	1.000	RE
Chlorobenzene	108-90-7	2.80E-02	RE	0.115	RE	0.456	RE	1.094	RE	1.000	RE
Chloroethane	75-00-3	6.10E-03	RE	0.019	RE	0.245	RE	0.588	RE	1.000	RE
Chloroform	67-66-3	6.80E-03	RE	0.029	RE	0.498	RE	1.194	RE	1.000	RE
Chloromethane	74-87-3	3.30E-03	RE	0.009	RE	0.204	RE	0.490	RE	1.000	RE
2-Chloronaphthalene	91-58-7	6.62E-02	e	0.322	e	0.828	e	1.986	e	0.990	e
2-Chlorophenol	95-57-8	8.00E-03	RE	0.035	RE	0.560	RE	1.345	RE	1.000	RE
2-Chlorotoluene	95-49-8	3.99E-02	e	0.173	e	0.541	e	1.298	e	1.000	e
4-Chlorotoluene	106-43-4	4.70E-02	e	0.204	e	0.538	e	1.291	e	1.000	e
Dibromochloromethane	124-48-1	3.20E-03	RE	0.018	RE	1.570	RE	3.768	RE	1.000	RE
1,2-Dichlorobenzene	95-50-1	4.10E-02	RE	0.193	RE	0.711	RE	1.706	RE	1.000	RE
1,3-Dichlorobenzene	541-73-1	5.80E-02	RE	0.270	RE	0.711	RE	1.706	RE	1.000	RE
1,4-Dichlorobenzene	106-46-7	4.20E-02	RE	0.196	RE	0.711	RE	1.706	RE	1.000	RE
Dichlorodifluoromethane	75-71-8	9.00E-03	RE	0.038	RE	0.507	RE	1.218	RE	1.000	RE
1,1-Dichloroethane	75-34-3	6.70E-03	RE	0.026	RE	0.382	RE	0.918	RE	1.000	RE
1,1-Dichloroethylene	75-35-4	1.20E-02	RE	0.044	RE	0.372	RE	0.893	RE	1.000	RE
cis-1,2-Dichloroethylene	156-59-2	7.67E-03	e	0.029	e	0.367	e	0.881	e	1.000	e
trans-1,2-Dichloroethylene	156-60-5	1.06E-02	e	0.040	e	0.367	e	0.881	e	1.000	e
1,2-Dichloropropane	78-87-5	7.80E-03	RE	0.032	RE	0.458	RE	1.100	RE	1.000	RE
1,3-Dichloropropene	542-75-6	4.30E-03	RE	0.018	RE	0.447	RE	1.072	RE	1.000	RE
Diisopropyl ether (DIPE)	108-20-3										
1,4-Dioxane	123-91-1	3.30E-04	RE	0.001	RE	0.332	RE	0.797	RE	1.000	RE
Ethanol	64-17-5										
Ethylbenzene	100-41-4										

**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, K <sub>p</sub>		Relative Contribution of Permeability Coefficient, B		Lag Time, τ <sub>event</sub>		Duration of Event, t*		Fraction Absorbed Water, FA	
		(cm/hr)		(unitless)		(hr/event)		(hr)		(unitless)	
Ethylene dibromide (EDB)	106-93-4										
Ethylene dichloride (EDC)	107-06-2										
Ethyl-tert-butyl-ether (ETBE)	637-92-3										
n-Hexane	110-54-3	7.74E-02	e	0.276	e	0.319	e	0.767	e	1.000	e
Isopropylbenzene (Cumene)	98-82-8	6.36E-02	e	0.268	e	0.495	e	1.189	e	1.000	e
4-Isopropyltoluene	99-87-6	1.52E-01	e	0.676	e	0.594	e	2.319	e	1.000	e
Methanol	67-56-1										
Methyl ethyl ketone	78-93-3	9.60E-04	RE	0.003	RE	0.270	RE	0.647	RE	1.000	RE
Methyl iodide	74-88-4	2.50E-03	RE	0.012	RE	0.666	RE	1.600	RE	1.000	RE
Methyl butyl ketone	591-78-6	4.15E-03	e	0.016	e	0.383	e	0.918	e	1.000	e
Methyl isobutyl ketone	108-10-1	2.70E-03	RE	0.010	RE	0.387	RE	0.930	RE	1.000	RE
Methyl tertiary butyl ether (MTBE)	1634-04-4										
Methylene chloride	75-09-2	3.50E-03	RE	0.013	RE	0.319	RE	0.765	RE	1.000	RE
Nitrobenzene	98-95-3	5.07E-03	e	0.022	e	0.514	e	1.234	e	1.000	e
n-Propylbenzene	103-65-1	9.74E-02	e	0.411	e	0.495	e	1.189	e	1.000	e
Styrene	100-42-5	3.70E-02	RE	0.146	RE	0.408	RE	0.980	RE	1.000	RE
1,1,1,2-Tetrachloroethane	630-20-6	1.57E-02	e	0.078	e	0.916	e	2.198	e	0.990	e
1,1,2,2-Tetrachloroethane	79-34-5	6.90E-03	RE	0.035	RE	0.931	RE	2.235	RE	1.000	RE
1,2,4,5-Tetrachlorobenzene	95-94-3	1.02E-01	e	0.575	e	1.702	e	4.084	e	0.950	e
Tetrachloroethylene	127-18-4	3.30E-02	RE	0.166	RE	0.906	RE	2.176	RE	1.000	RE
Tetrahydrofuran	109-99-9	1.62E-03	e	0.005	e	0.266	e	0.640	e	1.000	e
Tertiary-amyl-methyl-ether (TAME)	994-05-8										
Tertiary-butyl-alcohol (TBA)	75-65-0										
Toluene	108-88-3										
1,2,4-Trichlorobenzene	120-82-1	6.60E-02	RE	0.343	RE	1.110	RE	2.665	RE	1.000	RE
1,3,5-Trichlorobenzene	108-70-3	8.90E-02	e	0.461	e	1.091	e	2.619	e	0.970	e
1,1,1-Trichloroethane	71-55-6	1.30E-02	RE	0.056	RE	0.596	RE	1.431	RE	1.000	RE
1,1,2-Trichloroethane	79-00-5	6.40E-03	RE	0.029	RE	0.596	RE	1.431	RE	1.000	RE
Trichloroethylene	79-01-6	1.20E-02	RE	0.051	RE	0.581	RE	1.395	RE	1.000	RE
Trichlorofluoromethane	75-69-4	1.30E-02	RE	0.057	RE	0.628	RE	1.507	RE	1.000	RE
1,2,3-Trichloropropane	96-18-4	1.06E-02	e	0.050	e	0.704	e	1.689	e	1.000	e
1,1,2-Trichlorotrifluoroethane	76-13-1	1.55E-02	e	0.082	e	1.178	e	2.827	e	0.970	e
1,2,4-Trimethylbenzene	95-63-6	8.63E-02	e	0.364	e	0.495	e	1.189	e	1.000	e
1,3,5-Trimethylbenzene	108-67-8	9.31E-02	e	0.393	e	0.495	e	1.189	e	1.000	e
Vinyl chloride*	75-01-4	5.60E-03	RE	0.017	RE	0.239	RE	0.573	RE	1.000	RE
Xylenes (total)	1330-20-7										
SVOCs											
Acenaphthene	83-32-9										
Acenaphthylene	208-96-8	8.84E-02	e	0.419	e	0.747	e	1.792	e	0.990	e
Acrylamide	79-06-1	2.20E-04	RE	0.001	RE	0.266	RE	0.639	RE	1.000	RE
Acrylic acid	79-10-7	1.23E-03	e	0.004	e	0.266	e	0.639	e	1.000	e

**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, $K_p$		Relative Contribution of Permeability Coefficient, B		Lag Time, $\tau_{event}$		Duration of Event, $t^*$		Fraction Absorbed Water, FA	
		(cm/hr)		(unitless)		(hr/event)		(hr)		(unitless)	
Aniline	62-53-3	1.90E-03	RE	0.007	RE	0.354	RE	0.850	RE	1.000	RE
Anthracene	120-12-7										
Aroclor 1016	12674-11-2	2.84E-01	e	1.754	e	2.913	e	11.739	e	0.900	e
Aroclor 1221	11104-28-2	1.51E-01	e	0.821	e	1.399	e	5.378	e	0.950	e
Aroclor 1242	53469-21-9	2.53E-01	e	1.590	e	3.268	e	13.050	e	0.870	e
Aroclor 1248	12672-29-6	4.11E-01	e	2.736	e	5.001	e	20.968	e	0.800	e
Aroclor 1254	11097-69-1	4.56E-01	e	3.170	e	7.129	e	30.256	e	0.700	e
Aroclor 1260	11096-82-5	3.84E-01	e	2.861	e	13.359	e	56.222	e	0.550	e
Azobenzene	103-33-3	2.12E-01	e	1.101	e	1.102	e	4.274	e	0.920	e
Benzidine	92-87-5	1.10E-03	RE	0.006	RE	1.150	RE	2.759	RE	1.000	RE
Benzo(a)anthracene	56-55-3										
Benzo(a)pyrene	50-32-8										
Benzo(b)fluoranthene	205-99-2										
Benzo(g,h,i)perylene	191-24-2	1.19E+00	e	7.590	e	3.710	e	16.620	e	0.700	e
Benzo(k)fluoranthene	207-08-9										
Benzoic acid	65-85-0	5.70E-03	RE	0.024	RE	0.515	RE	1.235	RE	1.000	RE
Benzyl alcohol	100-51-6	2.03E-03	e	0.008	e	0.423	e	1.016	e	1.000	e
Bis(2-chloroethyl) ether	111-44-4	1.80E-03	RE	0.008	RE	0.675	RE	1.620	RE	1.000	RE
Bis(2-chloroisopropyl)ether	108-60-1	8.81E-03	e	0.044	e	0.954	e	2.289	e	0.980	e
Bis(2-ethylhexyl)phthalate	117-81-7	2.50E-02	RE	0.190	RE	16.639	RE	39.933	RE	0.800	RE
4-Bromophenyl phenyl ether	101-55-3	1.86E-01	e	1.130	e	2.611	e	10.145	e	0.900	e
Butyl benzyl phthalate	85-68-7	4.42E-02	e	0.300	e	5.904	e	14.169	e	0.900	e
Carbazole	86-74-8	2.49E-02	e	0.124	e	0.908	e	2.180	e	0.990	e
p-Chloroaniline	106-47-8	4.18E-03	e	0.018	e	0.545	e	1.308	e	1.000	e
4-Chlorophenyl phenyl ether	7005-72-3	2.40E-01	e	1.321	e	1.472	e	5.786	e	0.950	e
Chrysene	218-01-9										
Dibenzo(a,h)anthracene	53-70-3										
Dibenzofuran	132-64-9	7.87E-02	e	0.392	e	0.920	e	2.208	e	0.980	e
1,2-Dibromo-3-chloropropane	96-12-8	4.42E-03	e	0.026	e	2.215	e	5.316	e	0.950	e
Dibutyl phthalate	84-74-2	2.40E-02	RE	0.154	RE	3.864	RE	9.273	RE	0.900	RE
3,3-Dichlorobenzidine	91-94-1	1.30E-02	RE	0.078	RE	2.801	RE	6.722	RE	1.000	RE
2,4-Dichlorophenol	120-83-2	2.10E-02	RE	0.101	RE	0.874	RE	2.098	RE	1.000	RE
Diethyl phthalate	84-66-2	3.90E-03	RE	0.022	RE	1.874	RE	4.497	RE	1.000	RE
2,4-Dimethylphenol	105-67-9	1.10E-02	RE	0.046	RE	0.516	RE	1.238	RE	1.000	RE
2,6-Dimethylphenol	576-26-1										
Dimethyl phthalate	131-11-3	1.40E-03	RE	0.007	RE	1.305	RE	3.132	RE	1.000	RE
1,3-Dinitrobenzene	99-65-0	2.16E-03	e	0.011	e	0.919	e	2.205	e	0.980	e
2,4-Dinitrophenol	51-28-5	1.50E-03	RE	0.008	RE	1.148	RE	2.756	RE	1.000	RE
2,4-Dinitrotoluene	121-14-2	3.10E-03	RE	0.016	RE	1.119	RE	2.686	RE	1.000	RE
2,6-Dinitrotoluene	606-20-2	2.10E-03	RE	0.011	RE	1.119	RE	2.686	RE	1.000	RE
4-Amino-2,6-dinitrotoluene	19406-51-0	6.69E-03	e	0.036	e	1.336	e	3.207	e	0.970	e

**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, $K_p$		Relative Contribution of Permeability Coefficient, B		Lag Time, $\tau_{event}$		Duration of Event, $t^*$		Fraction Absorbed Water, FA	
		(cm/hr)		(unitless)		(hr/event)		(hr)		(unitless)	
2-Amino-4,6-dinitrotoluene	35572-78-2	8.79E-03	<i>e</i>	0.047	<i>e</i>	1.336	<i>e</i>	3.207	<i>e</i>	0.970	<i>e</i>
Di(2-ethylhexyl)adipate	103-23-1	3.03E+00	<i>e</i>	22.409	<i>e</i>	12.504	<i>e</i>	57.849	<i>e</i>	0.010	<i>e</i>
Di-n-octylphthalate	117-84-0	4.60E+00	<i>e</i>	34.995	<i>e</i>	16.182	<i>e</i>	75.351	<i>e</i>	0.010	<i>e</i>
1,2-Diphenylhydrazine	122-66-7	1.30E-02	<i>RE</i>	0.068	<i>RE</i>	1.150	<i>RE</i>	2.759	<i>RE</i>	1.000	<i>RE</i>
Diphenylamine	122-39-4	2.66E-02	<i>e</i>	0.133	<i>e</i>	0.932	<i>e</i>	2.237	<i>e</i>	0.980	<i>e</i>
Ethylene glycol	107-21-1	1.15E-04	<i>e</i>	0.000	<i>e</i>	0.234	<i>e</i>	0.562	<i>e</i>	1.000	<i>e</i>
Ethylene thiourea	96-45-7	1.70E-04	<i>RE</i>	0.001	<i>RE</i>	0.368	<i>RE</i>	0.883	<i>RE</i>	1.000	<i>RE</i>
Fluoranthene	206-44-0										
Fluorene	86-73-7										
Formaldehyde	50-00-0	1.80E-03	<i>RE</i>	0.004	<i>RE</i>	0.157	<i>RE</i>	0.376	<i>RE</i>	1.000	<i>RE</i>
Hexachlorobenzene	118-74-1	1.30E-01	<i>RE</i>	0.867	<i>RE</i>	4.218	<i>RE</i>	16.214	<i>RE</i>	0.900	<i>RE</i>
Hexachlorobutadiene	87-68-3	8.10E-02	<i>RE</i>	0.503	<i>RE</i>	3.094	<i>RE</i>	7.425	<i>RE</i>	0.900	<i>RE</i>
Hexachlorocyclopentadiene	77-47-4	5.31E-02	<i>e</i>	0.337	<i>e</i>	3.543	<i>e</i>	8.503	<i>e</i>	0.950	<i>e</i>
Hexachloroethane	67-72-1	3.00E-02	<i>RE</i>	0.178	<i>RE</i>	2.266	<i>RE</i>	5.438	<i>RE</i>	1.000	<i>RE</i>
Hexachlorophene	70-30-4	3.09E-01	<i>e</i>	2.397	<i>e</i>	19.978	<i>e</i>	82.811	<i>e</i>	0.500	<i>e</i>
HMX	2691-41-0	4.82E-06	<i>e</i>	0.000	<i>e</i>	4.790	<i>e</i>	11.496	<i>e</i>	0.940	<i>e</i>
Indeno(1,2,3-cd)pyrene	193-39-5	1.00E+00	<i>RE</i>	6.654	<i>RE</i>	3.780	<i>RE</i>	16.827	<i>RE</i>	0.600	<i>RE</i>
Isophorone	78-59-1	3.40E-03	<i>RE</i>	0.015	<i>RE</i>	0.635	<i>RE</i>	1.523	<i>RE</i>	1.000	<i>RE</i>
Maleic anhydride	108-31-6	5.25E-03	<i>e</i>	0.020	<i>e</i>	0.372	<i>e</i>	0.894	<i>e</i>	1.000	<i>e</i>
2-Methyl-4,6-dinitrophenol	534-52-1	3.10E-03	<i>RE</i>	0.017	<i>RE</i>	1.376	<i>RE</i>	3.302	<i>RE</i>	1.000	<i>RE</i>
2-Methylnaphthalene	91-57-6	7.20E-02	<i>e</i>	0.330	<i>e</i>	0.656	<i>e</i>	1.575	<i>e</i>	0.980	<i>e</i>
2-Methylphenol	95-48-7	7.70E-03	<i>RE</i>	0.031	<i>RE</i>	0.430	<i>RE</i>	1.033	<i>RE</i>	1.000	<i>RE</i>
3-Methylphenol	108-39-4	7.80E-03	<i>RE</i>	0.031	<i>RE</i>	0.430	<i>RE</i>	1.033	<i>RE</i>	1.000	<i>RE</i>
4-Methylphenol	106-44-5	7.70E-03	<i>RE</i>	0.031	<i>RE</i>	0.430	<i>RE</i>	1.033	<i>RE</i>	1.000	<i>RE</i>
Methyl-2,4,6-trinitrophenylnitramine	479-45-8	8.68E-04	<i>e</i>	0.006	<i>e</i>	4.264	<i>e</i>	10.235	<i>e</i>	0.950	<i>e</i>
m-Phenylenediamine	108-45-2	2.17E-04	<i>e</i>	0.001	<i>e</i>	0.424	<i>e</i>	1.018	<i>e</i>	1.000	<i>e</i>
Naphthalene	91-20-3										
2-Nitroaniline	88-74-4	5.76E-03	<i>e</i>	0.026	<i>e</i>	0.623	<i>e</i>	1.496	<i>e</i>	1.000	<i>e</i>
3-Nitroaniline	99-09-2	3.14E-03	<i>e</i>	0.014	<i>e</i>	0.623	<i>e</i>	1.496	<i>e</i>	1.000	<i>e</i>
4-Nitroaniline	100-01-6	1.36E-03	<i>e</i>	0.006	<i>e</i>	0.623	<i>e</i>	1.496	<i>e</i>	1.000	<i>e</i>
Nitroglycerin	55-63-0	1.77E-03	<i>e</i>	0.010	<i>e</i>	1.966	<i>e</i>	4.718	<i>e</i>	0.970	<i>e</i>
2-Nitrophenol	88-75-5	4.00E-03	<i>RE</i>	0.018	<i>RE</i>	0.642	<i>RE</i>	1.541	<i>RE</i>	1.000	<i>RE</i>
4-Nitrophenol	100-02-7	4.80E-03	<i>RE</i>	0.022	<i>RE</i>	0.642	<i>RE</i>	1.541	<i>RE</i>	1.000	<i>RE</i>
2-Nitrotoluene	88-72-2	9.73E-03	<i>e</i>	0.044	<i>e</i>	0.616	<i>e</i>	1.479	<i>e</i>	1.000	<i>e</i>
3-Nitrotoluene	99-08-1	9.73E-03	<i>e</i>	0.044	<i>e</i>	0.616	<i>e</i>	1.479	<i>e</i>	1.000	<i>e</i>
4-Nitrotoluene	99-99-0	9.73E-03	<i>e</i>	0.044	<i>e</i>	0.616	<i>e</i>	1.479	<i>e</i>	1.000	<i>e</i>
n-Nitrosodimethylamine	62-75-9	2.50E-04	<i>RE</i>	0.001	<i>RE</i>	0.277	<i>RE</i>	0.665	<i>RE</i>	1.000	<i>RE</i>
n-Nitrosodi-n-propylamine	621-64-7	2.30E-03	<i>RE</i>	0.010	<i>RE</i>	0.572	<i>RE</i>	1.373	<i>RE</i>	1.000	<i>RE</i>
n-Nitrosodiphenylamine	86-30-6	1.50E-02	<i>RE</i>	0.079	<i>RE</i>	1.378	<i>RE</i>	3.307	<i>RE</i>	1.000	<i>RE</i>
n-Nitrosopyrrolidine*	930-55-2	6.19E-04	<i>e</i>	0.002	<i>e</i>	0.382	<i>e</i>	0.918	<i>e</i>	1.000	<i>e</i>
Pentachlorobenzene	608-93-5	1.75E-01	<i>e</i>	1.066	<i>e</i>	2.653	<i>e</i>	10.270	<i>e</i>	0.940	<i>e</i>



**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, $K_p$		Relative Contribution of Permeability Coefficient, B		Lag Time, $\tau_{event}$		Duration of Event, $t^*$		Fraction Absorbed Water, FA	
		(cm/hr)		(unitless)		(hr/event)		(hr)		(unitless)	
Pentachloronitrobenzene	82-68-8	4.20E-02	RE	0.276	RE	4.831	RE	11.595	RE	0.900	RE
Pentachlorophenol	87-86-5	3.90E-01	RE	2.467	RE	3.326	RE	13.821	RE	0.900	RE
Pentaerythritol tetranitrate	78-11-5	9.55E-03	e	0.065	e	6.197	e	14.873	e	0.950	e
Phenanthrene	85-01-8	1.40E-01	RE	0.740	RE	1.064	RE	4.110	RE	1.000	RE
Phenol	108-95-2	4.30E-03	RE	0.016	RE	0.359	RE	0.861	RE	1.000	RE
Polychlorinated biphenyls (PCBs)	1336-36-3	3.41E-01	e	2.366	e	7.038	e	29.140	e	0.750	e
Pyrene	129-00-0										
RDX	121-82-4	6.42E-04	e	0.003	e	0.973	e	2.336	e	0.980	e
2,4,5-Trichlorophenol	95-95-4	2.34E-02	e	0.126	e	1.341	e	3.219	e	0.980	e
2,4,6-Trichlorophenol	88-06-2	3.50E-02	RE	0.187	RE	1.364	RE	3.275	RE	1.000	RE
1,3,5-Trinitrobenzene	99-35-4	9.13E-04	e	0.005	e	1.642	e	3.940	e	0.980	e
2,4,6-Trinitrotoluene (TNT)	118-96-7	1.75E-03	e	0.010	e	1.967	e	4.721	e	0.980	e
<b>Pesticides</b>											
Acetochlor	34256-82-1	2.11E-03	e	0.013	e	3.410	e	8.184	e	0.970	e
Acifluorfen	62476-59-9	2.63E-05	e	0.000	e	11.152	e	26.766	e	0.900	e
Acrolein	107-02-8	6.50E-04	RE	0.002	RE	0.220	RE	0.527	RE	1.000	RE
Alachlor	15972-60-8	8.22E-03	e	0.052	e	3.397	e	8.152	e	0.920	e
Aldicarb	116-06-3	1.08E-03	e	0.006	e	1.223	e	2.935	e	0.980	e
Aldicarb sulfone	1646-88-4	3.28E-05	e	0.980	e	1.847	e	7.121	e	0.950	e
Aldrin	309-00-2	1.40E-03	RE	0.010	RE	11.891	RE	28.538	RE	1.000	RE
alpha-Hexachlorocyclohexane	319-84-6	2.42E-02	e	0.158	e	4.472	e	10.733	e	0.920	e
Ametryn	834-12-8	6.78E-03	e	0.039	e	1.972	e	4.733	e	0.970	e
Atrazine	1912-24-9	7.13E-03	e	0.040	e	1.697	e	4.073	e	0.950	e
Baygon	114-26-1										
Butylate	2008-41-5	3.36E-02	e	0.190	e	1.734	e	4.163	e	0.980	e
beta-Hexachlorocyclohexane	319-85-7	2.42E-02	e	0.158	e	4.472	e	10.733	e	0.950	e
4-(2,4-Dichlorophenoxy) butyric acid (2,4-DB)	94-82-6	2.02E-02	e	0.122	e	2.611	e	6.266	e	0.970	e
Captan	133-06-2	1.20E-03	RE	0.008	RE	5.134	RE	12.321	RE	1.000	RE
Carbaryl	63-25-2	4.21E-03	e	0.023	e	1.408	e	3.380	e	0.980	e
Carbofuran	1563-66-2	3.01E-03	e	0.017	e	1.824	e	4.376	e	0.980	e
Carboxin	5234-68-4	7.51E-03	e	0.044	e	2.186	e	5.246	e	0.970	e
Chloramben	133-90-4	4.80E-03	e	0.027	e	1.504	e	3.609	e	0.980	e
Chlordane (technical)	12789-03-6	1.83E-01	e	1.421	e	20.726	e	81.956	e	0.550	e
Chlordane, gamma	57-74-9	3.80E-02	RE	0.294	RE	21.214	RE	50.914	RE	0.700	RE
Chlorothalonil	1897-45-6	1.90E-02	RE	0.116	RE	3.304	RE	7.931	RE	0.900	RE
Chlorpyrifos	2921-88-2	2.05E-02	e	0.148	e	9.664	e	23.193	e	0.900	e
Coumaphos	56-72-4	9.55E-03	e	0.070	e	11.307	e	27.138	e	0.880	e
Cyanazine	21725-46-2	9.71E-04	e	0.006	e	2.343	e	5.623	e	0.970	e
Dacthal	1861-32-1	2.81E-02	e	0.197	e	7.604	e	18.250	e	0.900	e
Dalapon, sodium salt	75-99-0	2.85E-03	e	0.013	e	0.664	e	1.595	e	1.000	e
DDD	72-54-8	1.80E-01	RE	1.234	RE	6.648	RE	25.989	RE	0.800	RE

**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, $K_p$		Relative Contribution of Permeability Coefficient, B		Lag Time, $\tau_{event}$		Duration of Event, $t^*$		Fraction Absorbed Water, FA	
		(cm/hr)		(unitless)		(hr/event)		(hr)		(unitless)	
DDE	72-55-9	1.60E-01	RE	1.067	RE	6.478	RE	25.080	RE	0.800	RE
DDT	50-29-3	2.70E-01	RE	1.948	RE	10.450	RE	42.512	RE	0.700	RE
DEF	78-48-8	1.59E-01	e	1.083	e	6.071	e	23.524	e	0.850	e
delta-Hexachlorocyclohexane	319-86-8	1.63E-02	e	0.107	e	4.471	e	10.731	e	0.950	e
Demeton	8065-48-3	5.17E-03	e	0.032	e	2.942	e	7.061	e	0.970	e
Diazinon	333-41-5	1.11E-02	e	0.075	e	5.324	e	12.777	e	0.920	e
Dicamba	1918-00-9	2.37E-03	e	0.014	e	1.818	e	4.364	e	0.980	e
2,4-Dichlorophenoxy acetic acid (2,4-D)	94-75-7	4.89E-03	e	0.028	e	1.818	e	4.364	e	0.980	e
Dichloroprop (2,4-DP)	120-36-5	1.09E-02	e	0.064	e	2.179	e	5.229	e	0.970	e
Dieldrin	60-57-1	1.20E-02	RE	0.092	RE	14.622	RE	35.093	RE	0.800	RE
Dimethoate	60-51-5	1.26E-04	e	0.001	e	2.022	e	4.852	e	0.970	e
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	88-85-7	1.90E-02	e	0.113	e	2.329	e	5.588	e	0.970	e
Diquat	85-00-7	2.58E-07	e	0.000	e	8.884	e	21.321	e	0.920	e
Disulfoton	298-04-4	1.63E-02	e	0.104	e	3.619	e	8.685	e	0.950	e
Diuron	330-54-1	4.56E-03	e	0.027	e	2.124	e	5.098	e	0.970	e
Endosulfan	115-29-7	2.85E-03	e	0.022	e	19.983	e	47.959	e	0.800	e
Endothall	145-73-3	2.54E-03	e	0.013	e	1.160	e	2.784	e	0.990	e
Endrin	72-20-8	1.20E-02	RE	0.092	RE	14.622	RE	35.093	RE	0.800	RE
Endrin aldehyde	7421-93-4	2.07E-01	e	1.555	e	14.304	e	57.011	e	0.680	e
Endrin Ketone	53494-70-5	3.84E-02	e	0.288	e	14.287	e	34.289	e	0.830	e
Eptam	759-94-4	1.35E-02	e	0.072	e	1.208	e	2.898	e	0.990	e
Ethoprop	13194-48-4	8.23E-03	e	0.049	e	2.393	e	5.743	e	0.970	e
Fenamiphos	22224-92-6			0.000	e	0.000	e	0.000	e	0.000	e
Fenthion	55-38-9	4.58E-03	e	0.029	e	3.806	e	9.134	e	0.950	e
Fluometuron	2164-17-2			0.000	e	0.000	e	0.000	e	0.000	e
Fonofos	944-22-9	2.89E-02	e	0.174	e	2.519	e	6.047	e	0.970	e
gamma-Hexachlorocyclohexane	58-89-9	1.10E-02	RE	0.071	RE	4.570	RE	10.969	RE	0.900	RE
Glyphosate	1071-83-6	1.57E-05	e	0.000	e	0.930	e	2.233	e	0.990	e
Guthion	86-50-0	1.18E-03	e	0.008	e	6.294	e	15.104	e	0.930	e
Heptachlor	76-44-8	8.60E-03	RE	0.064	RE	13.271	RE	31.852	RE	0.800	RE
Heptachlor epoxide	1024-57-3	1.81E-02	e	0.137	e	15.924	e	38.217	e	0.860	e
Hexazinone	51235-04-2	1.61E-03	e	0.010	e	2.722	e	6.532	e	0.970	e
Malathion	121-75-5	7.24E-04	e	0.005	e	7.445	e	17.868	e	0.910	e
Maleic hydrazide	123-33-1	9.70E-05	e	0.000	e	0.446	e	1.071	e	1.000	e
Maneb	12427-38-2			0.000	e	0.000	e	0.000	e	0.000	e
Methomyl	16752-77-5	4.95E-04	e	0.002	e	0.852	e	2.044	e	0.990	e
Methoxychlor	72-43-5	1.01E-01	e	0.723	e	9.069	e	35.106	e	0.820	e
2-Methyl-4-chlorophenoxyacetic acid (MCPA)	94-74-6	2.06E-02	e	0.112	e	1.397	e	3.354	e	0.980	e
MCPP	93-65-2	1.16E-02	e	0.066	e	1.674	e	4.019	e	0.970	e
Metolachlor	51218-45-2	3.33E-03	e	0.022	e	4.084	e	9.803	e	0.950	e
Metribuzin	21087-64-9	1.76E-04	e	0.001	e	1.667	e	4.000	e	0.970	e

**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, $K_p$		Relative Contribution of Permeability Coefficient, B		Lag Time, $\tau_{event}$		Duration of Event, $t^*$		Fraction Absorbed Water, FA	
		(cm/hr)		(unitless)		(hr/event)		(hr)		(unitless)	
Mirex	2385-85-5	2.54E+01	e	228.246	e	119.368	e	561.456	e	0.000	e
Naled	300-76-5	1.33E-04	e	0.001	e	14.265	e	34.236	e	0.860	e
o,o,o-Triethylphosphorothioate	126-68-1	6.80E-03	e	0.037	e	1.355	e	3.252	e	0.970	e
Oxamyl	23135-22-0	1.52E-05	e	0.000	e	1.777	e	4.265	e	0.970	e
Paraquat	4685-14-7	6.16E-08	e	0.000	e	2.897	e	6.953	e	0.960	e
ethyl-Parathion	56-38-2	1.30E-02	RE	0.084	RE	4.570	RE	10.969	RE	0.900	RE
methyl-Parathion	298-00-0	3.47E-03	e	0.022	e	3.132	e	7.517	e	0.950	e
Pendimethalin	40487-42-1	1.48E-01	e	0.952	e	3.955	e	15.232	e	0.890	e
Phenylmercuric acetate	62-38-4	7.97E-05	e	0.001	e	8.083	e	19.400	e	0.890	e
Phorate	298-02-2	9.21E-03	e	0.057	e	3.020	e	7.248	e	0.960	e
Picloram	1918-02-1	6.14E-03	e	0.037	e	2.366	e	5.679	e	0.970	e
Prometon	1610-18-0	6.90E-03	e	0.040	e	1.921	e	4.610	e	0.970	e
Pronamide	23950-58-5	1.33E-02	e	0.082	e	2.859	e	6.861	e	0.960	e
Propachlor	1918-16-7			0.000	e	0.000	e	0.000	e	0.000	e
Propanil	709-98-8	8.75E-03	e	0.050	e	1.750	e	4.201	e	0.970	e
Propazine	139-40-2	1.14E-02	e	0.067	e	2.033	e	4.880	e	0.970	e
Propham	122-42-9	8.95E-03	e	0.046	e	1.060	e	2.545	e	0.990	e
Silvex (2,4,5-TP)	93-72-1	1.32E-02	e	0.083	e	3.397	e	8.153	e	0.950	e
Simazine	122-34-9	6.50E-03	e	0.036	e	1.416	e	3.399	e	0.980	e
Strychnine	57-24-9	3.52E-04	e	0.002	e	7.845	e	18.828	e	0.910	e
Tebuthiuron	34014-18-1	1.27E-03	e	0.007	e	1.997	e	4.793	e	0.970	e
Terbacil	5902-51-2			0.000	e	0.000	e	0.000	e	0.000	e
Terbufos	13071-79-9	2.26E-02	e	0.148	e	4.336	e	10.406	e	0.930	e
Terbutryn	886-50-0	2.07E-02	e	0.124	e	2.364	e	5.674	e	0.970	e
Toxaphene	8001-35-2	1.20E-02	RE	0.093	RE	22.397	RE	53.754	RE	0.800	RE
Triallate	2303-17-5	3.24E-02	e	0.217	e	5.346	e	12.830	e	0.920	e
2,4,5-Trichlorophenoxy acetic acid (2,4,5-T)	93-76-5	8.42E-03	e	0.052	e	2.817	e	6.762	e	0.970	e
Trifluralin	1582-09-8	6.73E-02	e	0.474	e	7.934	e	19.041	e	0.870	e
Warfarin	81-81-2	3.84E-03	e	0.026	e	5.605	e	13.451	e	0.940	e
<b>Metals</b>											
Aluminum	7429-90-5	1.00E-03	RE	NA		NA		NA		NA	
Antimony	7440-36-0	1.00E-03	RE	NA		NA		NA		NA	
Arsenic	7440-38-2										
Barium	7440-39-3										
Beryllium	7440-41-7	1.00E-03	RE	NA		NA		NA		NA	
Cadmium	7440-43-9										
Chromium (III) total chromium	7440-47-3										
Chromium (VI)	18540-29-9										
Copper	7440-50-8	1.00E-03	RE	NA		NA		NA		NA	
Lead	7439-92-1										
Manganese	7439-96-5	1.00E-03	RE	NA		NA		NA		NA	

**Table E-2**  
**Parameters for Dermal Contact Pathway**

Chemicals	CAS #	Permeability Constant, $K_p$ (cm/hr)	Relative Contribution of Permeability Coefficient, B (unitless)	Lag Time, $\tau_{event}$ (hr/event)	Duration of Event, $t^*$ (hr)	Fraction Absorbed Water, FA (unitless)
Mercury	7439-97-6	1.00E-03	RE	NA	NA	NA
Molybdenum	7439-98-7	1.00E-03	RE	NA	NA	NA
Nickel	7440-02-0	2.00E-04	RE	NA	NA	NA
Selenium	7782-49-2					
Silver	7440-22-4	6.00E-04	RE	NA	NA	NA
Strontium	7440-24-6	1.00E-03	RE	NA	NA	NA
Thallium chloride	7791-12-0	1.00E-03	RE	NA	NA	NA
Vanadium	7440-62-2	1.00E-03	RE	NA	NA	NA
Zinc	7440-66-6	6.00E-04	RE	NA	NA	NA
<b>Inorganics</b>						
Ammonia	7664-41-7	1.00E-03	RE	NA	NA	NA
Cyanide	57-12-5	1.00E-03	RE	NA	NA	NA
Cyanide (as Sodium Cyanide)	143-33-9	1.00E-03	RE	NA	NA	NA
Cyanogen bromide	506-68-3	1.00E-03	RE	NA	NA	NA
Fluoride (as Sodium Fluoride)	7681-49-4	1.00E-03	RE	NA	NA	NA
Perchlorate	14797-73-0	1.00E-03	RE	NA	NA	NA
White phosphorus	7723-14-0	1.00E-03	RE	NA	NA	NA
<b>Petroleum Hydrocarbons</b>						
<b>TPH-GR0</b>						
Aliphatics - > C6-C8	NA	NA		NA	NA	NA
Aliphatics - > C8-C10	NA	NA		NA	NA	NA
Aromatics - >C8-C10	NA	NA		NA	NA	NA
<b>TPH-DR0</b>						
Aliphatics - >C10-C12	NA	NA		NA	NA	NA
Aliphatics - >C12-C16	NA	NA		NA	NA	NA
Aliphatics - >C16-C21	NA	NA		NA	NA	NA
Aromatics - >C10-C12	NA	NA		NA	NA	NA
Aromatics - >C12-C16	NA	NA		NA	NA	NA
Aromatics - >C16-C21	NA	NA		NA	NA	NA
<b>TPH-ORO</b>						
Aliphatics - >C21-C35	NA	NA		NA	NA	NA
Aromatics - >C21-C35	NA	NA		NA	NA	NA

Notes:

e - Estimated by RAGS Part E

RE - RAGS Part E

Colors:

Yellow - Some or all toxicity values identified

Orange - Lead is evaluated separately using IEUBK model

White - Chemicals in MRBCA Tanks guidance

**Table E-3**  
**Physical and Chemical Properties of Chemicals**

Chemicals	CAS #	MCL	Molecular Weight, MW	Water Solubility, S	Henry's Law Constant, H	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>	Soil-Water Partition Coefficient, K <sub>d</sub>	Diffusion Coefficient in Air, D <sub>i</sub>	Diffusion Coefficient in Water, D <sub>w</sub>	Vapor Pressure, P	Octanol-Water Partition Coefficient, K <sub>ow</sub>
		(mg/L)	(g/mol)	(mg/L)	(L-water/L-air)	(cm <sup>3</sup> /g)	(L/kg)	(cm <sup>2</sup> /s)	(cm <sup>2</sup> /s)	(mmHg)	(cm <sup>3</sup> /g)
<b>VOCs</b>											
Acetone	67-64-1		58	1.00E+06	1.59E-03	5.75E-01	NA	1.24E-01	1.14E-05	2.27E+02	5.80E-01
Acetonitrile	75-05-8		41	1.00E+06	1.41E-03	1.56E+01	NA	1.30E-01	1.70E-05	9.00E+01	4.57E-01
Acrylonitrile	107-13-1		53	7.45E+04	5.66E-03	8.50E-01	NA	1.08E-01	1.34E-05	1.10E+02	1.62E+00
Allyl alcohol	107-18-6		58	3.17E+05	2.05E-04	2.95E+01	NA	1.14E-01	1.10E-05	2.63E+01	1.48E+00
Allyl chloride	107-05-1		81	1.00E+06	3.12E-05	5.00E+01	NA	9.80E-02	1.08E-05	3.60E+02	8.51E+01
Benzene	71-43-2										
1,1-Biphenyl	92-52-4		154	6.94E+00	1.67E-02	1.40E+03	NA	4.04E-02	8.20E-06	2.94E+02	5.71E+03
Bis(chloromethyl) ether	542-88-1		115	2.20E+04	8.45E-03	1.20E+00	NA	8.87E-02	9.40E-06	3.00E+01	3.76E+00
Bromochloromethane	74-97-5		129	2.40E+04	3.69E-02	2.75E+01	NA	9.65E-02	1.12E-05	1.06E+02	2.09E+01
Bromodichloromethane	75-27-4	0.08	164	6.74E+03	6.56E-02	5.50E+01	NA	2.98E-02	1.06E-05	5.84E+01	4.07E+01
Bromoform	75-25-2	0.08	253	3.10E+03	2.19E-02	8.71E+01	NA	1.49E-02	1.03E-05	5.60E+00	6.17E+01
Bromomethane	74-83-9		95	1.50E+04	2.60E-01	9.00E+00	NA	7.30E-02	1.20E-05	1.64E+03	1.51E+01
n-Butylbenzene	104-51-8		130	1.40E+01	5.40E-01	2.80E+03	NA	7.50E-02	7.80E-06	8.14E-01	1.95E+04
sec-Butylbenzene	135-98-8		130	1.70E+01	7.70E-01	2.20E+03	NA	7.50E-02	7.80E-06	1.25E+00	1.23E+04
tert-Butylbenzene	98-06-6		130	3.00E+01	5.00E-01	2.20E+03	NA	7.50E-02	7.80E-06	1.76E+00	1.51E+04
Carbon disulfide	75-15-0		76	1.19E+03	1.24E+00	4.57E+01	NA	1.04E-01	1.00E-05	3.40E+02	8.71E+01
Carbon tetrachloride	56-23-5	0.005	154	7.93E+02	1.25E+00	1.74E+02	NA	7.80E-02	8.80E-06	1.12E+02	2.75E+02
Chlorobenzene	108-90-7		113	4.72E+02	1.52E-01	2.19E+02	NA	7.30E-02	8.70E-06	1.21E+01	4.37E+02
Chloroethane	75-00-3		65	5.70E+03	4.50E-01	1.50E+01	NA	1.00E-01	1.20E-05	1.20E+03	3.80E+01
Chloroform	67-66-3	0.08	119	7.92E+03	1.52E-01	3.98E+01	NA	1.04E-01	1.00E-05	1.98E+02	3.31E+01
Chloromethane	74-87-3		51	8.20E+03	9.80E-01	3.50E+01	NA	1.10E-01	6.50E-06	3.77E+03	1.23E+01
2-Chloronaphthalene	91-58-7		160	1.20E+01	1.30E-02	1.60E+03	NA	2.50E-02	8.80E-06	1.70E-02	6.51E+03
2-Chlorophenol	95-57-8		129	2.20E+04	1.60E-02	3.88E+02	NA	5.01E-02	9.46E-06	1.42E+00	1.45E+02
2-Chlorotoluene	95-49-8		127	1.54E+02	1.35E-01	4.07E+02	NA	7.01E-02	8.01E-06	3.90E-03	1.59E+03
4-Chlorotoluene	106-43-4		127	1.18E+02	1.33E-01	4.96E+02	NA	6.76E-02	7.96E-06	2.27E+00	2.02E+03
Dibromochloromethane	124-48-1	0.08	208	2.60E+03	3.21E-02	6.31E+01	NA	1.96E-02	1.05E-05	1.50E+01	5.01E+01
1,2-Dichlorobenzene	95-50-1	0.6	147	1.56E+02	7.79E-02	6.17E+02	NA	6.90E-02	7.90E-06	1.36E+00	1.91E+03
1,3-Dichlorobenzene	541-73-1		150	1.60E+02	7.80E-02	6.20E+02	NA	6.90E-02	7.90E-06	2.30E+00	1.91E+03
1,4-Dichlorobenzene	106-46-7	0.075	147	7.38E+01	9.96E-02	6.17E+02	NA	6.90E-02	7.90E-06	1.06E+00	1.91E+03
Dichlorodifluoromethane	75-71-8		120	2.80E+02	4.10E+00	5.80E+01	NA	8.00E-02	1.10E-05	4.80E+03	6.54E+01
1,1-Dichloroethane	75-34-3		99	5.10E+03	2.30E-01	3.20E+01	NA	7.40E-02	1.10E-05	2.28E+02	5.75E+01
1,1-Dichloroethylene	75-35-4	0.007	97	2.25E+03	1.07E+00	5.89E+01	NA	9.00E-02	1.04E-05	5.91E+02	1.32E+02
cis-1,2-Dichloroethylene	156-59-2	0.07	97	3.50E+03	1.67E-01	3.55E+01	NA	7.36E-02	1.13E-05	1.75E+02	7.24E+01
trans-1,2-Dichloroethylene	156-60-5	0.1	97	6.30E+03	3.85E-01	5.25E+01	NA	7.07E-02	1.19E-05	3.52E+02	1.18E+02
1,2-Dichloropropane	78-87-5	0.005	113	2.80E+03	1.15E-01	4.37E+01	NA	7.82E-02	8.73E-06	5.00E+01	1.78E+02
1,3-Dichloropropene	542-75-6		111	2.80E+03	7.26E-01	4.57E+01	NA	6.26E-02	1.00E-05	3.12E+01	5.62E+01
Diisopropyl ether (DIPE)	108-20-3										
1,4-Dioxane	123-91-1		88	1.00E+06	1.97E-04	1.70E+01	NA	2.30E-01	1.00E-05	3.80E+01	4.79E-01
Ethanol	64-17-5										
Ethylbenzene	100-41-4										
Ethylene dibromide (EDB)	106-93-4										
Ethylene dichloride (EDC)	107-06-2										

**Table E-3**  
**Physical and Chemical Properties of Chemicals**

Chemicals	CAS #	MCL	Molecular Weight, MW	Water Solubility, S	Henry's Law Constant, H	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>	Soil-Water Partition Coefficient, K <sub>d</sub>	Diffusion Coefficient in Air, D <sub>i</sub>	Diffusion Coefficient in Water, D <sub>w</sub>	Vapor Pressure, P	Octanol-Water Partition Coefficient, K <sub>ow</sub>
		(mg/L)	(g/mol)	(mg/L)	(L-water/L-air)	(cm <sup>3</sup> /g)	(L/kg)	(cm <sup>2</sup> /s)	(cm <sup>2</sup> /s)	(mmHg)	(cm <sup>3</sup> /g)
Ethyl-tert-butyl-ether (ETBE)	637-92-3										
n-Hexane	110-54-3		86	9.50E+00	7.38E+01	8.90E+02	NA	2.00E-01	7.77E-06	1.52E+02	1.95E+03
Isopropylbenzene (Cumene)	98-82-8		120	6.13E+01	3.57E+00	4.54E+02	NA	7.50E-02	7.10E-06	4.60E+00	2.82E+03
4-Isopropyltoluene	99-87-6		134	1.72E+01	4.66E-01	2.29E+03	NA	5.72E-02	6.73E-06	1.08E+00	1.38E+04
Methanol	67-56-1										
Methyl ethyl ketone	78-93-3		72	2.23E+05	2.33E-03	4.50E+00	NA	8.95E-02	9.80E-06	9.10E+01	1.80E+00
Methyl iodide	74-88-4		142	1.39E+04	2.16E-01	1.58E+02	NA	1.02E-01	1.17E-05	3.79E+02	3.55E+01
Methyl butyl ketone	591-78-6		100	1.79E+04	3.38E-03	1.79E+01	NA	6.96E-02	7.75E-06	1.11E+01	3.04E+01
Methyl isobutyl ketone	108-10-1		100	1.90E+04	5.66E-03	1.34E+02	NA	7.50E-02	7.80E-06	1.45E+02	1.45E+01
Methyl tertiary butyl ether (MTBE)	1634-04-4										
Methylene chloride	75-09-2	0.005	85	1.30E+04	8.98E-02	1.17E+01	NA	1.01E-01	1.17E-05	4.55E+02	2.19E+01
Nitrobenzene	98-95-3		123	2.09E+03	9.84E-04	6.46E+01	NA	7.60E-02	8.60E-06	2.44E-01	6.46E+01
n-Propylbenzene	103-65-1		120	5.22E+01	4.31E-01	7.41E+02	NA	7.50E-02	7.80E-06	2.71E+00	5.37E+03
Styrene	100-42-5	0.1	104	3.10E+02	1.13E-01	7.76E+02	NA	7.10E-02	8.00E-06	6.24E+00	7.94E+02
1,1,1,2-Tetrachloroethane	630-20-6		168	1.10E+03	9.92E-02	7.90E+01	NA	7.10E-02	7.90E-06	1.22E+01	8.57E+02
1,1,2,2-Tetrachloroethane	79-34-5		168	2.97E+03	1.41E-02	9.33E+01	NA	7.10E-02	7.90E-06	5.17E+00	1.55E+02
1,2,4,5-Tetrachlorobenzene	95-94-3		216	3.00E-01	4.99E-02	1.60E+03	NA	2.11E-02	8.80E-06	5.40E-03	3.72E+04
Tetrachloroethylene	127-18-4	0.005	166	2.00E+02	7.54E-01	1.55E+02	NA	7.20E-02	8.20E-06	1.84E+01	9.23E+02
Tetrahydrofuran	109-99-9		72	1.00E+06	2.89E-03	9.50E-01	NA	9.80E-02	1.10E-05	1.59E+02	4.22E+00
Tertiary-amyl-methyl-ether (TAME)	994-05-8										
Tertiary-butyl-alcohol (TBA)	75-65-0										
Toluene	108-88-3	1									
1,2,4-Trichlorobenzene	120-82-1	0.07	181	3.00E+02	5.80E-02	1.78E+03	NA	3.00E-02	8.20E-06	3.36E+01	8.44E+03
1,3,5-Trichlorobenzene	108-70-3		181	6.01E+00	8.98E-02	7.08E+02	NA	6.25E-02	7.66E-06	1.11E-01	1.55E+04
1,1,1-Trichloroethane	71-55-6	0.2	133	1.33E+03	7.05E-01	1.10E+02	NA	7.80E-02	8.80E-06	1.24E+02	4.79E+02
1,1,2-Trichloroethane	79-00-5	0.005	133	4.42E+03	3.74E-02	5.01E+01	NA	7.80E-02	8.80E-06	2.52E+01	1.02E+02
Trichloroethylene	79-01-6	0.005	131	1.10E+03	4.22E-01	1.66E+02	NA	7.90E-02	9.10E-06	7.20E+01	2.95E+02
Trichlorofluoromethane	75-69-4		90	2.05E+03	3.97E+00	1.60E+02	NA	8.70E-02	1.30E-05	6.87E+02	1.35E+02
1,2,3-Trichloropropane	96-18-4		147	1.75E+03	1.41E-02	5.10E+01	NA	7.10E-02	7.90E-06	3.70E+00	3.19E+02
1,1,2-Trichlorotrifluoroethane	76-13-1		187	1.70E+02	2.16E+01	3.72E+02	NA	2.88E-02	8.07E-06	3.60E+02	1.23E+03
1,2,4-Trimethylbenzene	95-63-6		120	5.70E+01	2.53E-01	3.72E+03	NA	7.50E-02	7.10E-06	1.59E+00	4.47E+03
1,3,5-Trimethylbenzene	108-67-8		120	4.82E+01	3.60E-01	8.19E+02	NA	7.50E-02	7.10E-06	2.13E+00	5.01E+03
Vinyl chloride	75-01-4	0.002	63	2.76E+03	1.11E+00	1.86E+01	NA	1.06E-01	1.23E-06	2.80E+03	4.17E+01
Xylenes (total)	1330-20-7										
<b>SVOCs</b>											
Acenaphthene	83-32-9										
Acenaphthylene	208-96-8		152	3.93E+00	4.74E-03	6.92E+03	NA	4.39E-02	7.07E-06	2.90E-02	8.63E+03
Acrylamide	79-06-1		71	6.40E+05	4.10E-08	5.00E+01	NA	9.70E-02	1.28E-05	7.00E-03	1.56E-01
Acrylic acid	79-10-7		72	1.00E+06	4.80E-06	1.13E+00	NA	9.08E-02	1.06E-05	3.72E+00	2.77E+00
Aniline	62-53-3		93	3.60E+04	5.82E-05	9.12E+00	NA	7.00E-02	8.30E-06	6.69E-01	1.20E+01
Anthracene	120-12-7										
Aroclor 1016	12674-11-2		258	4.20E-01	1.19E-02	1.80E+05	NA	1.92E-02	6.60E-06	4.00E-04	3.98E+05
Aroclor 1221	11104-28-2		201	5.90E-01	1.41E-01	5.80E+03	NA	2.85E-02	7.00E-06	6.70E-03	5.01E+04

**Table E-3**  
**Physical and Chemical Properties of Chemicals**

Chemicals	CAS #	MCL  (mg/L)	Molecular Weight, MW  (g/mol)	Water Solubility, S  (mg/L)	Henry's Law Constant, H  (L-water/L-air)	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>  (cm <sup>3</sup> /g)	Soil-Water Partition Coefficient, K <sub>d</sub>  (L/kg)	Diffusion Coefficient in Air, D <sub>i</sub>  (cm <sup>2</sup> /s)	Diffusion Coefficient in Water, D <sub>w</sub>  (cm <sup>2</sup> /s)	Vapor Pressure, P  (mmHg)	Octanol-Water Partition Coefficient, K <sub>ow</sub>  (cm <sup>3</sup> /g)
Aroclor 1242	53469-21-9		267	3.40E-01	2.10E-02	6.30E+03	NA	1.86E-02	6.50E-06	4.06E-04	3.98E+05
Aroclor 1248	12672-29-6		300	6.00E-02	1.13E-01	2.77E+05	NA	1.56E-02	6.10E-06	4.94E-04	1.58E+06
Aroclor 1254	11097-69-1		327	5.70E-02	8.20E-02	5.30E+05	NA	1.56E-02	5.00E-06	7.71E-05	3.16E+06
Aroclor 1260	11096-82-5		376	8.00E-02	1.85E-01	6.70E+06	NA	1.16E-02	6.00E-06	4.05E-05	6.31E+06
Azobenzene	103-33-3		182	1.60E+00	1.89E-03	5.32E+04	NA	4.96E-02	6.36E-06	3.02E-04	5.86E+04
Benzidine	92-87-5		184	3.22E+02	1.59E-09	1.74E+05	NA	3.40E-02	1.50E-05	8.36E-08	2.19E+01
Benzo(a)anthracene	56-55-3										
Benzo(a)pyrene	50-32-8										
Benzo(b)fluoranthene	205-99-2										
Benzo(g,h,i)perylene	191-24-2		276	2.60E-04	5.82E-06	1.58E+06	NA	4.90E-02	5.65E-05	1.00E-10	5.01E+06
Benzo(k)fluoranthene	207-08-9										
Benzoic acid	65-85-0		122	3.50E+03	6.31E-05	6.00E-01	NA	5.36E-02	7.97E-06	6.51E-03	7.41E+01
Benzyl alcohol	100-51-6		108	4.00E+04	1.62E-05	1.20E+01	NA	8.00E-02	8.00E-06	1.06E-01	1.20E+01
Bis(2-chloroethyl)ether	111-44-4		143	1.72E+04	7.38E-04	1.55E+01	NA	6.90E-02	7.53E-06	1.34E+00	3.63E+01
Bis(2-chloroisopropyl)ether	108-60-1		171	1.70E+03	4.60E-03	5.70E+01	NA	6.30E-02	6.40E-06	8.50E-01	3.80E+02
Bis(2-ethylhexyl)phthalate	117-81-7	0.006	391	3.40E-01	4.18E-06	1.51E+07	NA	3.51E-02	3.66E-06	6.45E-06	2.45E+08
4-Bromophenyl phenyl ether	101-55-3		249	1.45E+00	4.80E-03	1.70E+04	NA	4.75E-02	6.28E-06	5.85E-04	1.78E+05
Butyl benzyl phthalate	85-68-7		312	2.69E+00	5.17E-05	5.75E+04	NA	1.74E-02	4.83E-06	1.20E-05	6.92E+04
Carbazole	86-74-8		167	7.48E+00	6.27E-07	3.39E+03	NA	3.90E-02	7.03E-06	2.66E-04	1.70E+03
p-Chloroaniline	106-47-8		128	5.30E+03	1.36E-05	6.61E+01	NA	4.83E-02	1.01E-05	2.35E-02	5.25E+01
4-Chlorophenyl phenyl ether	7005-72-3		205	1.43E+00	1.30E-02	1.31E+04	NA	4.89E-02	6.19E-06	1.66E-03	1.10E+05
Chrysene	218-01-9										
Dibenzo(a,h)anthracene	53-70-3										
Dibenzofuran	132-64-9		168	4.22E+00	8.73E-03	7.76E+03	NA	6.01E-02	1.00E-05	1.64E-03	9.92E+03
1,2-Dibromo-3-chloropropane	96-12-8	0.0002	236	1.23E+03	6.03E-03	2.80E+01	NA	7.00E-06	7.00E-06	7.60E-01	4.79E+02
Dibutyl phthalate	84-74-2		278	1.12E+01	3.85E-08	3.39E+04	NA	4.38E-02	7.86E-06	4.25E-05	4.07E+04
3,3-Dichlorobenzidine	91-94-1		253	3.11E+00	1.64E-07	7.24E+02	NA	1.94E-02	6.74E-06	2.20E-07	1.62E+03
2,4-Dichlorophenol	120-83-2		163	4.50E+03	1.30E-04	1.47E+02	NA	3.46E-02	8.77E-06	7.15E-02	6.31E+02
Diethyl phthalate	84-66-2		222	1.08E+03	1.85E-05	2.88E+02	NA	2.56E-02	6.35E-06	1.65E-03	4.42E+02
2,4-Dimethylphenol	105-67-9		122	7.87E+03	8.20E-05	2.09E+02	NA	5.84E-02	8.69E-06	1.26E-01	4.07E+02
2,6-Dimethylphenol	576-26-1		122	6.05E+03	2.73E-04	1.60E+03	NA	5.84E-02	8.69E-06	NA	NA
Dimethyl phthalate	131-11-3		194	4.00E+03	4.31E-06	4.00E+01	NA	5.68E-02	6.30E-06	9.12E-03	4.57E+01
1,3-Dinitrobenzene	99-65-0		168	5.33E+01	1.53E-05	1.06E+02	NA	2.80E-01	7.60E-06	2.49E-04	4.27E+01
2,4-Dinitrophenol	51-28-5		184	2.79E+03	1.82E-05	1.00E-02	NA	2.73E-02	9.06E-06	1.14E-04	5.37E+01
2,4-Dinitrotoluene	121-14-2		182	2.70E+02	3.80E-06	9.55E+01	NA	2.03E-01	7.06E-06	1.74E-04	1.50E+02
2,6-Dinitrotoluene	606-20-2		182	1.82E+02	3.06E-05	6.92E+01	NA	3.27E-02	7.26E-06	5.70E-04	1.50E+02
4-Amino-2,6-dinitrotoluene	19406-51-0		197	3.64E+01	1.74E-07	3.63E+02	NA	5.60E-02	7.31E-06	5.86E-07	4.17E+02
2-Amino-4,6-dinitrotoluene	35572-78-2		197	1.73E+01	1.19E-07	5.62E+02	NA	5.60E-02	7.30E-06	1.19E-07	6.31E+02
Di(2-ethylhexyl)adipate	103-23-1	0.4	371	1.71E-03	9.78E-01	3.80E+05	NA	3.56E-02	3.72E-06	8.25E-05	1.30E+08
Di-n-octylphthalate	117-84-0		391	2.00E-02	2.74E-03	2.39E+03	NA	1.51E-02	3.58E-06	4.47E-06	3.64E+08
1,2-Diphenylhydrazine	122-66-7		184	1.84E+03	1.42E-07	6.61E+02	NA	5.62E-02	5.70E-06	2.60E-05	1.14E+03
Diphenylamine	122-39-4		169	5.30E+01	1.39E-04	6.00E+02	NA	6.08E-02	6.30E-06	4.26E-03	1.96E+03
Ethylene glycol	107-21-1		62	1.00E+06	2.46E-06	4.00E+00	NA	1.08E-01	1.22E-05	7.00E-02	6.31E-02



**Table E-3**  
**Physical and Chemical Properties of Chemicals**

Chemicals	CAS #	MCL  (mg/L)	Molecular Weight, MW  (g/mol)	Water Solubility, S  (mg/L)	Henry's Law Constant, H  (L-water/L-air)	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>  (cm <sup>3</sup> /g)	Soil-Water Partition Coefficient, K <sub>d</sub>  (L/kg)	Diffusion Coefficient in Air, D <sub>i</sub>  (cm <sup>2</sup> /s)	Diffusion Coefficient in Water, D <sub>w</sub>  (cm <sup>2</sup> /s)	Vapor Pressure, P  (mmHg)	Octanol-Water Partition Coefficient, K <sub>ow</sub>  (cm <sup>3</sup> /g)
Ethylene thiourea	96-45-7		102	2.00E+04	1.26E-08	1.00E+01	NA	7.15E-02	1.02E-05	8.36E-02	3.23E-01
Fluoranthene	206-44-0										
Fluorene	86-73-7										
Formaldehyde	50-00-0		30	4.00E+05	1.38E-05	2.19E+00	NA	1.80E-01	2.00E-05	3.88E+03	2.24E+00
Hexachlorobenzene	118-74-1	0.001	285	6.20E+00	5.41E-02	5.50E+04	NA	5.42E-02	5.91E-06	1.23E-05	7.24E+05
Hexachlorobutadiene	87-68-3		261	3.23E+00	3.34E-01	5.37E+04	NA	5.61E-02	6.16E-06	1.77E-01	5.21E+04
Hexachlorocyclopentadiene	77-47-4	0.05	273	1.80E+00	1.11E+00	2.00E+05	NA	1.61E-02	7.21E-06	7.32E-02	4.22E+04
Hexachloroethane	67-72-1		237	5.00E+01	1.59E-01	1.78E+03	NA	2.50E-03	6.80E-06	4.72E-01	1.08E+04
Hexachlorophene	70-30-4		407	1.40E+02	2.25E-11	5.00E+03	NA	8.00E-02	8.00E-06	2.74E-12	8.36E+06
HMX	2691-41-0		296	1.40E+02	3.55E-08	3.70E+01	NA	3.74E-02	6.34E-06	4.75E-15	5.00E-02
Indeno(1,2,3-cd)pyrene	193-39-5		276	2.20E-05	6.56E-05	3.47E+06	NA	1.90E-02	5.66E-06	1.40E-10	4.98E+06
Isophorone	78-59-1		138	1.20E+04	2.72E-04	4.68E+01	NA	6.23E-02	6.76E-06	4.10E-01	4.15E+02
Maleic anhydride	108-31-6		98	4.91E+03	1.61E-04	2.57E+01	NA	9.50E-02	1.11E-05	1.34E-03	4.17E+01
2-Methyl-4,6-dinitrophenol	534-52-1		198	3.00E+03	1.07E-07	3.16E-02	NA	5.31E-02	7.27E-06	2.87E-05	1.17E+02
2-Methylnaphthalene	91-57-6		142	2.54E+01	1.85E-02	4.32E+03	NA	6.29E-02	7.20E-06	6.57E-02	5.20E+03
2-Methylphenol	95-48-7		108	2.60E+04	4.92E-05	9.12E+01	NA	7.40E-02	8.30E-06	3.20E-01	1.15E+02
3-Methylphenol	108-39-4		108	2.27E+04	3.55E-05	3.46E+01	NA	7.40E-02	1.00E-05	1.40E-01	1.15E+02
4-Methylphenol	106-44-5		108	2.15E+04	4.10E-05	4.90E+01	NA	7.40E-02	1.00E-05	1.30E-01	1.15E+02
Methyl-2,4,6-trinitrophenylnitramine	479-45-8		287	7.50E+01	8.31E-11	2.34E+02	NA	5.69E-02	6.40E-06	4.00E-10	1.10E+02
m-Phenylenediamine	108-45-2		108	2.38E+05	3.91E-09	1.10E+00	NA	6.63E-02	9.90E-06	2.28E-02	4.06E-01
Naphthalene	91-20-3										
2-Nitroaniline	88-74-4		138	1.26E+03	2.08E-05	2.69E+01	NA	5.99E-02	7.18E-06	4.75E-03	1.05E+02
3-Nitroaniline	99-09-2		138	4.56E+02	2.31E-07	3.94E+01	NA	6.73E-02	8.59E-06	1.39E-05	4.17E+01
4-Nitroaniline	100-01-6		138	6.49E+02	3.33E-08	1.12E+01	NA	6.69E-02	8.59E-06	2.86E-06	1.18E+01
Nitroglycerin	55-63-0		227	6.70E+04	3.40E-06	9.25E+01	NA	5.53E-02	7.34E-06	1.00E-04	1.00E+02
2-Nitrophenol	88-75-5		139	1.73E+04	2.21E-05	2.09E+01	NA	6.87E-02	8.47E-06	5.03E-02	2.23E+02
4-Nitrophenol	100-02-7		139	4.49E+03	3.24E-08	3.16E+00	NA	6.73E-02	8.66E-06	1.91E-05	5.33E+01
2-Nitrotoluene	88-72-2		137	6.00E+02	1.87E-03	1.41E+02	NA	6.47E-02	7.73E-06	1.50E-01	2.28E+02
3-Nitrotoluene	99-08-1		137	4.98E+02	2.24E-03	1.41E+02	NA	6.42E-02	7.69E-06	1.50E-01	2.28E+02
4-Nitrotoluene	99-99-0		137	4.00E+02	2.29E-03	1.41E+02	NA	6.40E-02	7.70E-06	1.20E-01	2.28E+02
n-Nitrosodimethylamine	62-75-9		74	1.00E+06	7.46E-05	1.20E+01	NA	1.34E-01	9.72E-06	5.37E+00	2.30E-01
n-Nitrosodi-n-propylamine	621-64-7		130	9.89E+03	9.35E-05	2.00E+01	NA	5.45E-02	8.17E-06	4.00E-01	2.24E+01
n-Nitrosodiphenylamine	86-30-6		198	3.51E+01	2.05E-04	1.29E+03	NA	3.12E-02	6.35E-06	9.88E-02	1.45E+03
n-Nitrosopyrrolidine	930-55-2		100	7.80E+05	7.48E-07	6.50E-01	NA	8.00E-02	8.00E-06	1.75E-01	1.70E+00
Pentachlorobenzene	608-93-5		250	1.33E+00	2.91E-02	4.00E+04	NA	6.70E-02	6.30E-06	1.67E-03	1.66E+05
Pentachloronitrobenzene	82-68-8		295	5.50E-01	3.28E-03	2.66E+04	NA	1.59E-02	6.10E-06	1.13E-04	1.07E+05
Pentachlorophenol	87-86-5	0.001	266	1.95E+03	1.00E-06	5.92E+02	NA	5.60E-02	6.10E-06	1.70E-05	5.50E+04
Pentaerythritol tetranitrate	78-11-5		316	2.66E+01	5.60E-05	6.29E+03	NA	4.48E-02	6.20E-06	8.63E-05	7.31E+03
Phenanthrene	85-01-8		178	9.94E-01	5.40E-03	1.41E+04	NA	3.33E-02	7.47E-06	6.80E-04	2.24E+04
Phenol	108-95-2		94	8.28E+04	1.63E-05	2.88E+01	NA	8.20E-02	9.10E-06	4.63E-01	3.24E+01
Polychlorinated biphenyls (PCBs)	1336-36-3	0.0005	326	4.30E-02	1.16E-02	3.09E+05	NA	1.04E-01	1.00E-05	7.60E-05	2.00E+06
Pyrene	129-00-0										
RDX	121-82-4		173	9.33E+02	2.28E-06	6.31E+01	NA	6.65E-02	6.39E-06	1.00E-09	7.41E+00



**Table E-3**  
**Physical and Chemical Properties of Chemicals**

Chemicals	CAS #	MCL  (mg/L)	Molecular Weight, MW  (g/mol)	Water Solubility, S  (mg/L)	Henry's Law Constant, H  (L-water/L-air)	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>  (cm <sup>3</sup> /g)	Soil-Water Partition Coefficient, K <sub>d</sub>  (L/kg)	Diffusion Coefficient in Air, D <sub>i</sub>  (cm <sup>2</sup> /s)	Diffusion Coefficient in Water, D <sub>w</sub>  (cm <sup>2</sup> /s)	Vapor Pressure, P  (mmHg)	Octanol-Water Partition Coefficient, K <sub>ow</sub>  (cm <sup>3</sup> /g)
2,4,5-Trichlorophenol	95-95-4		197	1.20E+03	1.78E-04	1.60E+03	NA	2.91E-02	7.03E-06	1.63E-02	2.79E+03
2,4,6-Trichlorophenol	88-06-2		197	8.00E+02	3.19E-04	3.81E+02	NA	3.18E-02	6.25E-06	1.18E-02	2.79E+03
1,3,5-Trinitrobenzene	99-35-4		213	2.78E+02	1.36E-08	1.41E+01	NA	8.00E-02	8.00E-06	9.90E-05	2.79E+01
2,4,6-Trinitrotoluene (TNT)	118-96-7		227	1.30E+02	1.87E-05	3.08E+02	NA	5.41E-02	6.57E-06	1.24E-04	9.85E+01
<b>Pesticides</b>											
Acetochlor	34256-82-1		270	2.23E+02	2.86E-06	2.00E+02	NA	5.01E-02	6.00E-06	3.40E-08	3.00E+02
Acifluorfen	62476-59-9		362	2.50E+05	8.31E-13	1.13E+02	NA	1.45E-02	4.40E-06	9.75E-09	2.36E+00
Acrolein	107-02-8		56	2.10E+05	4.90E-03	2.10E+01	NA	1.10E-01	1.20E-05	2.65E+02	7.94E-01
Alachlor	15972-60-8	0.002	270	2.40E+02	3.41E-07	1.91E+02	NA	1.94E-02	5.83E-06	2.20E-05	2.34E+03
Aldicarb	116-06-3	0.003	190	6.03E+03	5.90E-08	1.60E+01	NA	3.05E-02	7.20E-06	2.90E-05	2.29E+01
Aldicarb sulfone	1646-88-4	0.003	222	7.80E+03	1.38E-07	3.00E+00	NA	5.55E-02	5.79E-06	9.00E-05	2.16E-01
Aldrin	309-00-2		365	1.80E-01	6.97E-03	2.45E+06	NA	1.32E-02	4.86E-06	1.67E-05	5.62E+06
alpha-Hexachlorocyclohexane	319-84-6		291	2.00E+00	4.35E-04	1.23E+03	NA	1.42E-02	7.34E-06	4.26E-05	1.82E+04
Ametryn	834-12-8		227	1.85E+02	1.88E-07	3.89E+02	NA	4.24E-02	5.70E-06	1.81E-07	7.67E+02
Atrazine	1912-24-9	0.003	216	2.80E+01	1.83E-07	4.89E+02	NA	5.64E-02	5.58E-06	3.00E-07	6.60E+02
Baygon	114-26-1		209	1.86E+03	1.64E-05	1.60E+02	NA	5.67E-02	7.41E-06	NA	NA
Butylate	2008-41-5		217	4.60E+01	3.50E-03	1.26E+02	NA	4.89E-02	5.14E-06	1.30E-02	7.13E+03
beta-Hexachlorocyclohexane	319-85-7		291	2.40E-01	3.05E-05	1.26E+03	NA	1.42E-02	7.34E-06	4.90E-07	1.82E+04
4-(2,4-Dichlorophenoxy) butyric acid (2,4-DB)	94-82-6		249	5.30E+01	9.39E-08	5.30E+02	NA	4.41E-02	6.13E-06	1.82E-07	6.12E+03
Captan	133-06-2		301	3.30E+00	2.95E-04	1.98E+02	NA	1.83E-02	4.90E-06	7.50E-06	6.98E+01
Carbaryl	63-25-2		201	8.26E+01	5.37E-02	1.02E+02	NA	2.78E-02	5.60E-06	1.36E-06	2.24E+02
Carbofuran	1563-66-2	0.04	221	3.20E+01	1.27E-07	4.80E+01	NA	5.35E-02	5.40E-06	8.30E-06	2.00E+02
Carboxin	5234-68-4		235	1.99E+02	1.15E+01	8.46E+02	NA	4.48E-02	6.14E-06	4.82E-08	1.05E+03
Chloramben	133-90-4		206	7.00E+02	1.59E-05	1.90E+02	NA	5.71E-02	7.46E-06	1.94E-05	3.02E+02
Chlordane (technical)	12789-03-6		410	5.60E-02	1.99E-03	1.20E+05	NA	1.18E-02	4.37E-06	1.00E-05	3.98E+06
Chlordane, gamma	57-74-9	0.002	410	2.28E-02	4.11E-03	3.93E+05	NA	3.32E-02	4.65E-06	4.17E-06	9.25E+06
Chlorothalonil	1897-45-6		266	6.00E-01	8.20E-05	5.78E+03	NA	4.90E-02	6.57E-06	2.41E-06	2.88E+03
Chlorpyrifos	2921-88-2		351	4.00E-01	1.20E-04	1.86E+03	NA	4.85E-02	5.11E-06	1.87E-05	4.57E+04
Coumaphos	56-72-4		363	3.86E-01	2.17E-07	1.60E+04	NA	3.53E-02	4.81E-06	4.22E-09	1.82E+04
Cyanazine	21725-46-2		241	1.70E+02	1.05E+01	2.00E+02	NA	4.33E-02	5.83E-06	7.28E-09	5.25E+01
Dacthal	1861-32-1		332	2.20E-01	9.35E-06	4.68E+04	NA	4.20E-02	2.05E+00	1.13E-07	5.13E+04
Dalapon, sodium salt	75-99-0	0.2	143	7.43E+03	2.64E-06	2.30E+00	NA	6.98E-02	8.70E-06	1.30E-01	3.98E+01
DDD	72-54-8		320	9.00E-02	1.64E-04	1.00E+06	NA	1.69E-02	4.76E-06	8.66E-07	7.47E+05
DDE	72-55-9		318	1.20E-01	8.61E-04	4.47E+06	NA	1.44E-02	5.87E-06	5.66E-06	9.90E+05
DDT	50-29-3		354	2.50E-02	3.32E-04	2.63E+06	NA	1.37E-02	4.95E-06	3.93E-07	6.23E+06
DEF	78-48-8		315	2.30E+00	1.20E-05	3.16E+05	NA	1.45E-02	5.90E-06	1.38E-05	5.01E+05
delta-Hexachlorocyclohexane	319-86-8		291	3.14E+01	1.76E-05	4.26E+03	NA	4.50E-02	6.20E-06	2.87E-05	1.00E+04
Demeton	8065-48-3		258	7.20E+02	6.65E-03	2.69E+02	NA	4.56E-02	5.45E-06	1.00E-04	9.33E+02
Diazinon	333-41-5		304	4.00E+01	4.63E-06	2.29E+02	NA	1.80E-02	4.90E-06	8.40E-05	7.31E+03
Dicamba	1918-00-9		221	4.50E+03	8.94E-08	1.15E+02	NA	6.02E-02	6.69E-06	9.70E-05	1.38E+02
2,4-Dichlorophenoxy acetic acid (2,4-D)	94-75-7	0.07	221	6.77E+02	4.18E-07	8.91E+02	NA	5.90E-02	6.50E-06	2.40E-05	4.14E+02
Dichloroprop (2,4-DP)	120-36-5		235	2.30E+02	9.00E-07	2.86E-02	NA	4.70E-02	6.43E-06	1.60E-05	1.83E+03
Dieldrin	60-57-1		381	1.95E-01	6.19E-04	2.14E+04	NA	1.25E-02	4.74E-06	9.96E-07	2.82E+05

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Chemicals	CAS #	MCL  (mg/L)	Molecular Weight, MW  (g/mol)	Water Solubility, S  (mg/L)	Henry's Law Constant, H  (L-water/L-air)	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>  (cm <sup>3</sup> /g)	Soil-Water Partition Coefficient, K <sub>d</sub>  (L/kg)	Diffusion Coefficient in Air, D <sub>i</sub>  (cm <sup>2</sup> /s)	Diffusion Coefficient in Water, D <sub>w</sub>  (cm <sup>2</sup> /s)	Vapor Pressure, P  (mmHg)	Octanol-Water Partition Coefficient, K <sub>ow</sub>  (cm <sup>3</sup> /g)
Dimethoate	60-51-5		229	2.38E+04	4.31E-09	2.70E+01	NA	8.00E-02	8.00E-06	5.09E-06	1.90E+00
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	88-85-7	0.007	240	5.20E+01	1.87E-05	1.24E+02	NA	2.25E-02	6.25E-06	7.52E-02	4.71E+03
Diquat	85-00-7	0.02	344	7.08E+04	5.82E-12	2.04E+02	NA	5.52E-02	5.52E-06	1.00E-07	1.51E-03
Disulfoton	298-04-4		274	1.63E+01	1.64E-04	1.60E+00	NA	8.00E-02	8.00E-06	2.30E-04	7.24E+03
Diuron	330-54-1		233	4.20E+01	1.11E-04	3.80E+02	NA	5.40E-02	5.30E-06	1.00E-07	4.71E+02
Endosulfan	115-29-7		407	5.10E-01	4.59E-04	2.14E+03	NA	1.15E-02	4.55E-06	9.96E-06	6.92E+03
Endothall	145-73-3	0.1	186	1.00E+05	1.48E-13	1.23E+02	NA	5.72E-02	7.50E-06	1.80E-04	7.76E+01
Endrin	72-20-8	0.002	381	2.50E-01	3.08E-04	1.23E+04	NA	1.25E-02	4.74E-06	5.84E-07	2.82E+05
Endrin aldehyde	74-21-93-4		381	1.68E-02	1.80E-02	2.14E+06	NA	2.97E-02	3.83E-06	1.46E-05	2.75E+06
Endrin Ketone	53494-70-5		381	8.60E-01	3.66E-05	1.74E+05	NA	3.10E-02	4.46E-06	1.51E-06	2.14E+05
Eptam	759-94-4		189	3.70E+02	4.57E-03	2.40E+02	NA	5.35E-02	5.65E-06	1.60E-01	1.04E+03
Ethoprop	13194-48-4		242	7.50E+02	6.73E-06	1.22E+03	NA	4.16E-02	5.56E-06	3.80E-04	1.38E+03
Fenamiphos	22224-92-6		303	3.29E+02	4.96E-08	3.31E+02	NA	1.82E-02	4.88E-06	NA	NA
Fenthion	55-38-9		278	2.17E+01	2.13E-05	1.10E+03	NA	4.35E-02	5.42E-06	1.38E-04	1.15E+03
Fluometuron	2164-17-2		232	1.10E+02	7.38E-08	1.75E+02	NA	4.38E-02	5.66E-06	NA	NA
Fonofos	944-22-9		246	1.60E+01	2.21E-04	3.58E+03	NA	4.65E-02	5.52E-06	3.43E-01	1.00E+04
gamma-Hexachlorocyclohexane	58-89-9	0.0002	291	6.80E+00	5.74E-04	1.07E+03	NA	1.42E-02	7.34E-06	3.72E-05	1.81E+04
Glyphosate	1071-83-6	0.7	169	1.20E+04	1.67E-17	3.63E+03	NA	5.07E-02	8.30E-06	7.50E-08	2.51E-02
Guthion	86-50-0		317	9.00E-02	8.80E-11	2.51E+02	NA	4.11E-02	5.34E-06	4.70E-09	3.16E+02
Heptachlor	76-44-8	0.0004	373	1.80E-01	6.10E+01	1.41E+06	NA	1.12E-02	5.69E-06	3.26E-04	1.61E+06
Heptachlor epoxide	1024-57-3	0.0002	389	2.00E-01	3.90E-04	8.32E+04	NA	1.32E-02	4.23E-06	4.34E-06	8.04E+04
Hexazinone	51235-04-2		252	3.30E+04	1.69E-11	3.72E+01	NA	5.08E-02	5.11E-06	2.03E-07	1.42E+02
Malathion	121-75-5		330	1.43E+02	9.84E-07	1.80E+03	NA	1.50E-02	4.40E-06	7.90E-06	1.94E+02
Maleic hydrazide	123-33-1		112	6.00E+03	1.09E-09	4.15E+01	NA	9.00E-02	1.11E-05	7.50E-08	1.30E-01
Maneb	12427-38-2		295	6.00E+00	2.31E-05	5.50E+02	NA	1.59E-02	6.10E-06	NA	NA
Methomyl	16752-77-5		162	5.80E+04	7.54E-09	1.50E+01	NA	6.93E-02	1.00E-05	5.00E-05	4.07E+00
Methoxychlor	72-43-5	0.04	346	4.50E-02	6.48E-04	9.77E+04	NA	1.56E-02	4.46E-06	1.23E-06	4.65E+05
2-Methyl-4-chlorophenoxyacetic acid (MCPA)	94-74-6		201	1.17E+03	5.45E-08	8.90E+01	NA	5.12E-02	6.82E-06	6.99E-06	2.45E+03
MCPP	93-65-2		215	2.80E+02	1.00E-06	1.73E-02	NA	4.70E-02	6.36E-06	2.50E-05	1.36E+03
Metolachlor	51218-45-2		284	5.30E+02	3.69E-07	7.03E+02	NA	3.61E-02	5.10E-06	2.29E-06	7.87E+02
Metribuzin	21087-64-9		214	1.22E+03	7.42E-11	9.50E+01	NA	4.51E-02	5.98E-06	5.16E-05	2.36E+00
Mirex	2385-85-5		546	3.28E+00	2.11E-02	5.57E+03	NA	3.50E-02	4.08E-06	7.50E-07	1.00E+11
Naled	300-76-5		381	2.00E+03	2.05E-05	1.33E+02	NA	4.40E-02	6.80E-06	2.00E-04	3.98E+01
o,o,o-Triethylphosphorothioate	126-68-1		198	8.45E+02	2.08E-02	4.90E+02	NA	5.26E-02	6.24E-06	7.30E-01	4.37E+02
Oxamyl	23135-22-0	0.2	219	2.80E+05	9.72E-09	8.00E+00	NA	5.57E-02	5.75E-06	3.83E-07	6.32E-02
Paraquat	4685-14-7		257	6.20E+05	4.10E-08	1.55E+04	NA	3.74E-02	3.57E-06	1.45E-06	3.16E-05
ethyl-Parathion	56-38-2		291	1.18E+01	2.37E-05	5.60E+03	NA	1.70E-02	5.80E-06	1.73E-05	5.38E+03
methyl-Parathion	298-00-0		263	3.70E+01	4.10E-06	5.10E+03	NA	8.00E-02	8.00E-06	1.52E-05	5.61E+02
Pendimethalin	40487-42-1		281	2.75E-01	3.51E-05	1.91E+05	NA	3.81E-02	5.26E-06	7.31E-07	2.34E+05
Phenylmercuric acetate	62-38-4		337	4.70E+03	2.32E-08	6.70E+01	NA	8.00E-02	8.00E-06	3.04E-06	7.76E+00
Phorate	298-02-2		260	5.00E+01	2.36E-04	6.61E+02	NA	8.00E-02	8.00E-06	1.30E-03	2.33E+03
Picloram	1918-02-1	0.5	241	4.30E+02	1.66E+02	2.60E+01	NA	5.50E-02	7.27E-06	2.15E-06	8.71E+02
Prometon	1610-18-0		225	7.50E+02	8.12E-08	5.25E+02	NA	4.25E-02	5.54E-06	3.43E-06	7.59E+02

**Table E-3**  
**Physical and Chemical Properties of Chemicals**

Chemicals	CAS #	MCL  (mg/L)	Molecular Weight, MW  (g/mol)	Water Solubility, S  (mg/L)	Henry's Law Constant, H  (L-water/L-air)	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>  (cm <sup>3</sup> /g)	Soil-Water Partition Coefficient, K <sub>d</sub>  (L/kg)	Diffusion Coefficient in Air, D <sub>i</sub>  (cm <sup>2</sup> /s)	Diffusion Coefficient in Water, D <sub>w</sub>  (cm <sup>2</sup> /s)	Vapor Pressure, P  (mmHg)	Octanol-Water Partition Coefficient, K <sub>ow</sub>  (cm <sup>3</sup> /g)
Pronamide	23950-58-5		256	1.50E+01	7.83E-05	2.00E+02	NA	8.00E-02	8.00E-06	4.00E-04	3.76E+03
Propachlor	1918-16-7		212	6.13E+02	4.47E-06	2.63E+02	NA	8.03E-02	8.03E-06	NA	NA
Propanil	709-98-8		218	2.25E+02	1.85E-07	9.03E+02	NA	4.93E-02	6.59E-06	8.99E-07	9.43E+02
Propazine	139-40-2		230	8.60E+00	1.89E-07	1.55E+02	NA	4.40E-02	5.69E-06	1.23E-06	1.78E+03
Propham	122-42-9		179	3.20E+01	1.58E-06	8.90E+01	NA	5.71E-02	6.28E-06	1.35E-04	4.57E+02
Silvex (2,4,5-TP)	93-72-1	0.05	270	1.40E+02	3.71E-07	5.60E+01	NA	1.94E-02	5.80E-06	5.20E-06	4.78E+03
Simazine	122-34-9	0.004	202	5.70E+00	1.38E-07	1.38E+02	NA	4.90E-02	6.37E-06	9.10E-07	4.37E+02
Strychnine	57-24-9		334	1.60E+02	3.10E-12	7.94E+01	NA	8.00E-02	8.00E-06	1.67E-10	7.04E+01
Tebuthiuron	34014-18-1		228.31	2.50E+03	4.99E-11	3.13E+01	NA	5.62E-02	5.85E-06	2.03E-05	6.17E+01
Terbacil	5902-51-2		217	7.10E+02	4.92E-09	4.10E+01	NA	4.95E-02	6.61E-06	NA	NA
Terbufos	13071-79-9		288	5.07E+00	9.84E-04	6.61E+02	NA	4.18E-02	5.08E-06	2.96E-02	1.57E+04
Terbutryn	886-50-0		241	2.50E+01	1.30E-06	1.63E+03	NA	5.60E-02	6.00E-06	2.10E-06	5.50E+03
Toxaphene	8001-35-2	0.003	414	7.40E-01	2.46E-04	2.57E+05	NA	1.16E-02	4.34E-06	4.19E-06	6.24E+06
Triallate	2303-17-5		305	4.00E+00	7.91E-04	2.24E+03	NA	4.58E-02	4.84E-06	1.20E-04	3.72E+04
2,4,5-Trichlorophenoxyacetic acid (2,4,5-T)	93-76-5		255	2.78E+02	3.62E-07	5.30E+01	NA	8.00E-02	8.00E-06	3.61E-06	1.83E+03
Trifluralin	1582-09-8		335	8.11E+00	1.08E-03	1.38E+04	NA	1.49E-02	4.70E-06	1.10E-04	2.05E+05
Warfarin	81-81-2		308	1.70E+01	1.14E-07	9.19E+02	NA	1.63E-02	4.40E-06	1.16E-07	1.58E+03
<b>Metals</b>											
Aluminum	7429-90-5		27	NA	0.00E+00	NA	3.53E+02	NA	NA	NA	2.13E+00
Antimony	7440-36-0	0.006	122	NA	0.00E+00	NA	4.47E+01	NA	NA	NA	1.00E+00
Arsenic	7440-38-2										
Barium	7440-39-3										
Beryllium	7440-41-7	0.004	9	NA	0.00E+00	NA	2.29E+01	NA	NA	NA	3.72E+00
Cadmium	7440-43-9										
Chromium (III) total chromium	7440-47-3										
Chromium (VI)	18540-29-9										
Copper	7440-50-8		64	NA	0.00E+00	NA	3.98E+01	NA	NA	NA	2.69E-01
Lead	7439-92-1										
Manganese	7439-96-5		55	NA	0.00E+00	NA	5.01E+01	NA	NA	NA	1.00E+00
Mercury	7439-97-6		401	3.00E-02	4.67E-01	NA	4.00E-02	3.07E-02	6.30E-06	1.30E-03	3.38E-01
Molybdenum	7439-98-7		96	NA	0.00E+00	NA	2.00E+01	NA	NA	NA	1.00E+00
Nickel	7440-02-0		59	NA	0.00E+00	NA	1.59E+01	NA	NA	NA	2.69E-01
Selenium	7782-49-2										
Silver	7440-22-4		108	NA	0.00E+00	NA	1.00E+00	NA	NA	NA	1.00E+00
Strontium	7440-24-6		88	NA	0.00E+00	NA	2.00E+00	NA	NA	NA	1.00E+00
Thallium chloride	7791-12-0		240	2.90E+03	0.00E+00	NA	4.37E+01	NA	NA	NA	NA
Vanadium	7440-62-2		51	NA	0.00E+00	NA	1.00E+03	NA	NA	NA	1.00E+00
Zinc	7440-66-6		65	NA	0.00E+00	NA	1.59E+01	NA	NA	NA	3.38E-01
<b>Inorganics</b>											
Ammonia	7664-41-7		17	5.31E+05	1.36E-02	3.09E+00	NA	2.59E-01	6.93E-05	7.47E+03	1.69E+00
Cyanide	57-12-5		26	1.00E+05	0.00E+00	NA	9.90E+00	5.21E-01	2.28E-05	1.38E+01	2.03E-01
Cyanide (as Sodium Cyanide)	143-33-9	0.2	49	5.80E+05	0.00E+00	NA	NA	NA	6.64E-06	NA	2.00E-02
Cyanogen bromide	506-68-3		106	8.50E+03	2.05E-01	2.60E+01	NA	9.60E-02	1.00E-05	NA	NA

**Table E-3**  
**Physical and Chemical Properties of Chemicals**

Chemicals	CAS #	MCL	Molecular Weight, MW	Water Solubility, S	Henry's Law Constant, H	Organic Carbon Adsorption Coefficient, K <sub>oc</sub>	Soil-Water Partition Coefficient, K <sub>d</sub>	Diffusion Coefficient in Air, D <sub>i</sub>	Diffusion Coefficient in Water, D <sub>w</sub>	Vapor Pressure, P	Octanol-Water Partition Coefficient, K <sub>ow</sub>
		(mg/L)	(g/mol)	(mg/L)	(L-water/L-air)	(cm <sup>3</sup> /g)	(L/kg)	(cm <sup>2</sup> /s)	(cm <sup>2</sup> /s)	(mmHg)	(cm <sup>3</sup> /g)
Fluoride (as Sodium Fluoride)	7681-49-4	4	42	4.00E+04	0.00E+00	NA	NA	NA	6.15E-06	NA	1.70E-01
Perchlorate	14797-73-0		99.5	NA	0.00E+00	NA	NA	NA	NA	NA	NA
White phosphorus	7723-14-0		31	3.00E+00	5.65E-02	1.12E+03	NA	1.85E-01	1.68E-05	2.50E-02	1.20E+03
<b>Petroleum Hydrocarbons</b>											
<b>TPH-GR0</b>											
Aliphatics - > C6-C8	NA										
Aliphatics - > C8-C10	NA										
Aromatics - >C8-C10	NA										
<b>TPH-DR0</b>											
Aliphatics - >C10-C12	NA										
Aliphatics - >C12-C16	NA										
Aliphatics - >C16-C21	NA										
Aromatics - >C10-C12	NA										
Aromatics - >C12-C16	NA										
Aromatics - >C16-C21	NA										
<b>TPH-ORO</b>											
Aliphatics - >C21-C35	NA										
Aromatics - >C21-C35	NA										

Sources for properties:

**Regular underlined font:** Properties kept from department's Tanks MRBCA Guidance.

**Bold font:** CALM (1998) as revised in 2001, Table A4.

**Bold and italic font:** EPA Region IX, PRGs InterCalc Tables: Phys-Chem Data (10/01/02).

*Italic font:* Texas Commission on Environmental Quality's TRRP Chemical/Physical Properties Table; March, 2004.

**Regular font:** Idaho Risk Based Decision-Making for Remedial Action Guidance Document, Appendix G, 2003.

**Bold underlined font: Properties developed using the following equation:**

$$D_1 = \left( \frac{MW_2}{MW_1} \right)^{1/2} \times D_2$$

where,

D<sub>1</sub> = Diffusion coefficient of chemical 1 (cm<sup>2</sup>/s)  
D<sub>2</sub> = Diffusion coefficient of chemical 2 (cm<sup>2</sup>/s)  
MW<sub>1</sub> = Molecular weight of chemical 1 (g/mol)  
MW<sub>2</sub> = Molecular weight of chemical 2 (g/mol)

This equation comes from Handbook of Chemical Property Estimation Methods (Lyman et al., 1990).

MCLs: (Maximum Contaminant Level) USEPA (Winter 2004) Edition of Drinking Water Standards and Health Advisories.

**Table E-4**  
**Exposure Factors**

Parameter	Symbol	Unit	Default
Averaging Time for Carcinogen	AT <sub>c</sub>	year	70
Averaging Time for Non-Carcinogen	AT <sub>nc</sub>	year	=ED
<b>Body Weight:</b>			
Resident Child	BW	kg	15
Resident Adult	BW	kg	70
Non-Residential Worker	BW	kg	70
Construction Worker	BW	kg	70
<b>Exposure Duration:</b>			
Resident Child	ED	year	6
Resident Adult	ED	year	24
Non-Residential Worker	ED	year	25
Construction Worker	ED	year	1
<b>Exposure Frequency:</b>			
Resident Child	EF	day/year	350
Resident Adult	EF	day/year	350
Non-Residential Worker	EF	day/year	250
Construction Worker	EF	day/year	90
<b>Soil Ingestion Rate:</b>			
Resident Child	IR <sub>soil</sub>	mg/day	200
Resident Adult	IR <sub>soil</sub>	mg/day	100
Non-Residential Worker	IR <sub>soil</sub>	mg/day	100
Construction Worker	IR <sub>soil</sub>	mg/day	100
<b>Groundwater Ingestion Rate:</b>			
Resident Child	IR <sup>w</sup>	L/day	1
Resident Adult	IR <sup>w</sup>	L/day	2
<b>Indoor Inhalation Rate (hourly):</b>			
Resident Child	IR <sub>ai</sub>	m <sup>3</sup> /hr	0.416
Resident Adult	IR <sub>ai</sub>	m <sup>3</sup> /hr	0.833
Non-Residential Worker	IR <sub>ai</sub>	m <sup>3</sup> /hr	0.833
<b>Exposure Time for Indoor Inhalation:</b>			
Resident Child	ET <sub>in</sub>	hr/day	18
Resident Adult	ET <sub>in</sub>	hr/day	18
Non-Residential Worker	ET <sub>in</sub>	hr/day	18
<b>Indoor Inhalation Rate (daily):</b>			
Resident Child	IR <sub>a</sub>	m <sup>3</sup> /day	7.5
Resident Adult	IR <sub>a</sub>	m <sup>3</sup> /day	15.0
Non-Residential Worker	IR <sub>a</sub>	m <sup>3</sup> /day	15.0

**Table E-4**  
**Exposure Factors**

Parameter	Symbol	Unit	Default
<b>Outdoor Inhalation Rate (hourly):</b>			
Resident Child	$IR_{ao}$	$m^3/hr$	0.416
Resident Adult	$IR_{ao}$	$m^3/hr$	0.833
Non-Residential Worker	$IR_{ao}$	$m^3/hr$	0.833
Construction Worker	$IR_{ao}$	$m^3/hr$	1.62
<b>Exposure Time for Outdoor Inhalation:</b>			
Resident Child	$ET_{out}$	hr/day	6
Resident Adult	$ET_{out}$	hr/day	6
Non-Residential Worker	$ET_{out}$	hr/day	6
Construction Worker	$ET_{out}$	hr/day	10
<b>Outdoor Inhalation Rate (daily):</b>			
Resident Child	$IR_a$	$m^3/day$	2.5
Resident Adult	$IR_a$	$m^3/day$	5.0
Non-Residential Worker	$IR_a$	$m^3/day$	5.0
Construction Worker	$IR_a$	$m^3/day$	16.2
<b>Skin Surface Area for Incidental Dermal Contact with Soil:</b>			
Resident Child	$SA_{soil}$	$cm^2/day$	2800
Resident Adult	$SA_{soil}$	$cm^2/day$	5700
Non-Residential Worker	$SA_{soil}$	$cm^2/day$	3300
Construction Worker	$SA_{soil}$	$cm^2/day$	3300
<b>Skin Surface Area for Incidental Dermal Contact with Water:</b>			
Resident Child	$SA_{gw}$	$cm^2/day$	2800
Resident Adult	$SA_{gw}$	$cm^2/day$	5700
Non-Residential Worker	$SA_{gw}$	$cm^2/day$	3300
Construction Worker	$SA_{gw}$	$cm^2/day$	3300
<b>Skin Surface Area for Whole-Body Dermal Contact with Water:</b>			
Resident Child	$SA_{gw-wb}$	$cm^2/day$	6600
Resident Adult	$SA_{gw-wb}$	$cm^2/day$	18000
<b>Soil to Skin Adherence Factor:</b>			
Resident Child	AF	$mg/cm^2$	0.2
Resident Adult	AF	$mg/cm^2$	0.07
Non-Residential Worker	AF	$mg/cm^2$	0.2
Construction Worker	AF	$mg/cm^2$	0.3

**Table E-4**  
**Exposure Factors**

Parameter	Symbol	Unit	Default
<b>Event Frequency for Incidental Dermal Contact with Soil</b>			
Resident Child	$EV_{soil}$	event/day	1
Resident Adult	$EV_{soil}$	event/day	1
Non-Residential Worker	$EV_{soil}$	event/day	1
Construction Worker	$EV_{soil}$	event/day	1
<b>Event Frequency for Incidental Dermal Contact with Water</b>			
Resident Child	$EV_{gw}$	event/day	1
Resident Adult	$EV_{gw}$	event/day	1
Non-Residential Worker	$EV_{gw}$	event/day	1
Construction Worker	$EV_{gw}$	event/day	1
<b>Event Frequency for Whole-Body Dermal Contact with Water</b>			
Resident Child	$EV_{gw\_wb}$	event/day	1
Resident Adult	$EV_{gw\_wb}$	event/day	1
<b>Event Duration for Incidental Dermal Contact with Water</b>			
Resident Child	$t_{event}$	hr/event	1
Resident Adult	$t_{event}$	hr/event	1
Non-Residential Worker	$t_{event}$	hr/event	1
Construction Worker	$t_{event}$	hr/event	1
<b>Event Duration for Whole-Body Dermal Contact with Water</b>			
Resident Child	$t_{event\_wb}$	hr/event	0.33
Resident Adult	$t_{event\_wb}$	hr/event	0.25
<b>Target Risk Level</b>	TR	--	1.00E-05
<b>Target Hazard Quotient</b>	THQ	--	1

**Table E-5**  
**Fate and Transport Parameters**

Parameter	Symbol	Unit	Soil Type 1	Soil Type 2	Soil Type 3
<b>SOIL PARAMETERS:</b>					
Soil Source Dimension Parallel to Wind Direction	$W_a$	cm	1500	1500	1500
Depth to Subsurface Soil Sources	$d_{ts}$	cm	91.44	91.44	91.44
Depth of Surficial Soil Zone	$d_s$	cm	91.44	91.44	91.44
Depth to Soil Vapor Measurement	dsv	cm	91.44	91.44	91.44
<b>VADOSE ZONE:</b>					
Total Soil Porosity	$\theta_T$	$\text{cm}^3/\text{cm}^3\text{-soil}$	0.38	0.44	0.44
Volumetric Water Content	$\theta_{ws}$	$\text{cm}^3/\text{cm}^3$	0.08	0.17	0.21
Volumetric Air Content	$\theta_{as}$	$\text{cm}^3/\text{cm}^3$	<b>0.30</b>	<b>0.27</b>	<b>0.23</b>
Thickness	$h_v$	cm	<b>295</b>	<b>295</b>	<b>295</b>
Dry Soil Bulk Density	$\rho_s$	$\text{g}/\text{cm}^3$	1.5	1.5	1.5
Fractional Organic Carbon Content	$f_{ocv}$	$\text{g-C}/\text{g-soil}$	0.006	0.006	0.006
<b>SOIL IN CRACKS:</b>					
Total Soil Porosity	$\theta_{Tcrack}$	$\text{cm}^3/\text{cm}^3\text{-soil}$	0.38	0.44	0.44
Volumetric Water Content	$\theta_{wcrack}$	$\text{cm}^3/\text{cm}^3$	0.08	0.17	0.21
Volumetric Air Content	$\theta_{acrack}$	$\text{cm}^3/\text{cm}^3$	<b>0.30</b>	<b>0.27</b>	<b>0.23</b>
<b>CAPILLARY FRINGE:</b>					
Total Soil Porosity	$\theta_{Tcap}$	$\text{cm}^3/\text{cm}^3\text{-soil}$	0.38	0.44	0.44
Volumetric Water Content	$\theta_{wcap}$	$\text{cm}^3/\text{cm}^3$	<b>0.34</b>	<b>0.40</b>	<b>0.40</b>
Volumetric Air Content	$\theta_{acap}$	$\text{cm}^3/\text{cm}^3$	<b>0.038</b>	<b>0.044</b>	<b>0.044</b>
Thickness	$h_c$	cm	5	5	5
<b>GROUNDWATER PARAMETERS:</b>					
Depth to Groundwater	$L_{gw}$	cm	300	300	300
GW Source Dimension Perpendicular to GW Flow Direction	Y	cm	1500	1500	1500
GW Source Dimension Parallel to GW Flow Direction	$W_{ga}$	cm	1500	1500	1500
Total Porosity in the Saturated Zone*	$\theta_{TS}$	$\text{cm}^3/\text{cm}^3$	0.38	0.44	0.44
Dry Soil Bulk Density (Saturated Zone)*	$\rho_{ss}$	$\text{g}/\text{cm}^3$	1.5	1.5	1.5
Fractional Organic Carbon Content in the Saturated Zone*	$f_{ocs}$	$\text{g-C}/\text{g-soil}$	0.006	0.006	0.006



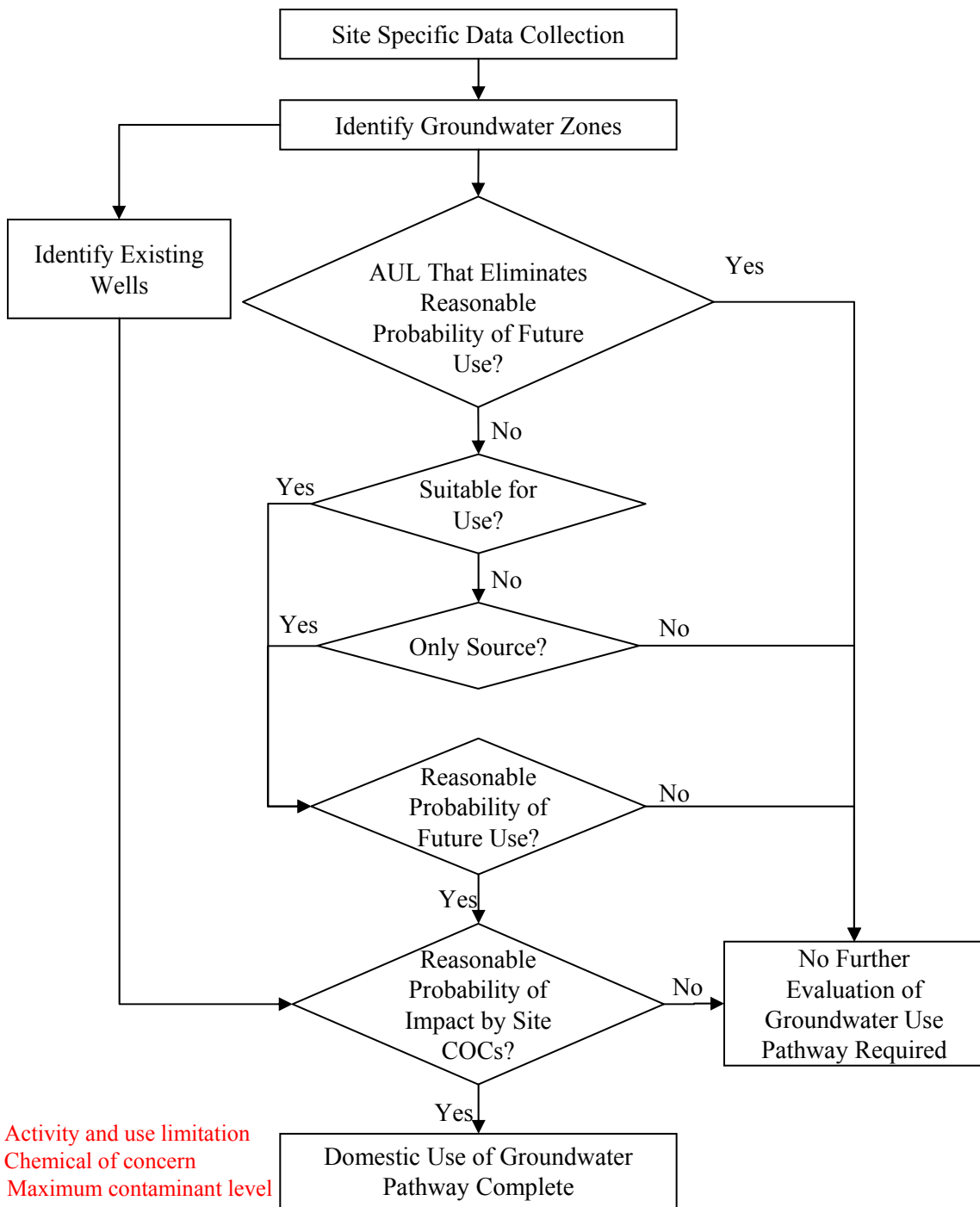
**Table E-5**  
**Fate and Transport Parameters**

Parameter	Symbol	Unit	Soil Type 1	Soil Type 2	Soil Type 3
Groundwater Mixing Zone Thickness	$\delta_{gw}$	cm	200	200	200
Hydraulic Conductivity in the Saturated Zone	K	cm/year	625000	625000	625000
Hydraulic Gradient in the Saturated Zone	i	cm/cm	0.004	0.004	0.004
Groundwater Darcy Velocity	$U_{gw}$	cm/year	<b>2500</b>	<b>2500</b>	<b>2500</b>
Infiltration Rate of Water Through Vadose Zone	I	cm/year	14	14	14
<b>AMBIENT AIR PARAMETERS:</b>					
Breathing Zone Height	$\delta_a$	cm	200	200	200
Inverse of Mean Concentration at Center of Square Source	Q/C	(g/m <sup>2</sup> -s)/(kg/m <sup>3</sup> )	81.64	81.64	81.64
Fraction of Vegetative Cover	V	m <sup>2</sup> /m <sup>2</sup>	0.5	0.5	0.5
Mean Annual Wind Speed	$U_m$	m/s	4.69	4.69	4.69
Equivalent Threshold Value of Windspeed	$U_t$	m/s	11.32	11.32	11.32
Windspeed Distribution Function from Cowherd et. al, 1985	F(x)	unitless	0.194	0.194	0.194
<b>ENCLOSED SPACE PARAMETERS:</b>					
<b>Enclosed Space Air Exchange Rate:</b>					
Residential Structure	ER	1/24 hrs	12.096	12.096	12.096
Non-Residential Structure	ER	1/24hrs	19.872	19.872	19.872
<b>Enclosed Space Volume/Infiltration Area:</b>					
Residential Structure	$L_B$	cm	200	200	200
Non-Residential Structure	$L_B$	cm	300	300	300
<b>Volatalization Factor for Domestic Water Use (K)</b>	K	L/m <sup>3</sup>	0.5	0.5	0.5
<b>Enclosed Space Foundation or Wall Thickness:</b>					
Residential Structure	$L_{crack}$	cm	15	15	15
Non-Residential Structure	$L_{crack}$	cm	15	15	15
<b>Area Fraction of Cracks in Foundation/Walls:</b>					
Residential Structure	$\eta$	cm <sup>2</sup> /cm <sup>2</sup>	0.001	0.001	0.001
Non-Residential Structure	$\eta$	cm <sup>2</sup> /cm <sup>2</sup>	0.001	0.001	0.001

Notes:

The values in **bold** are calculated .

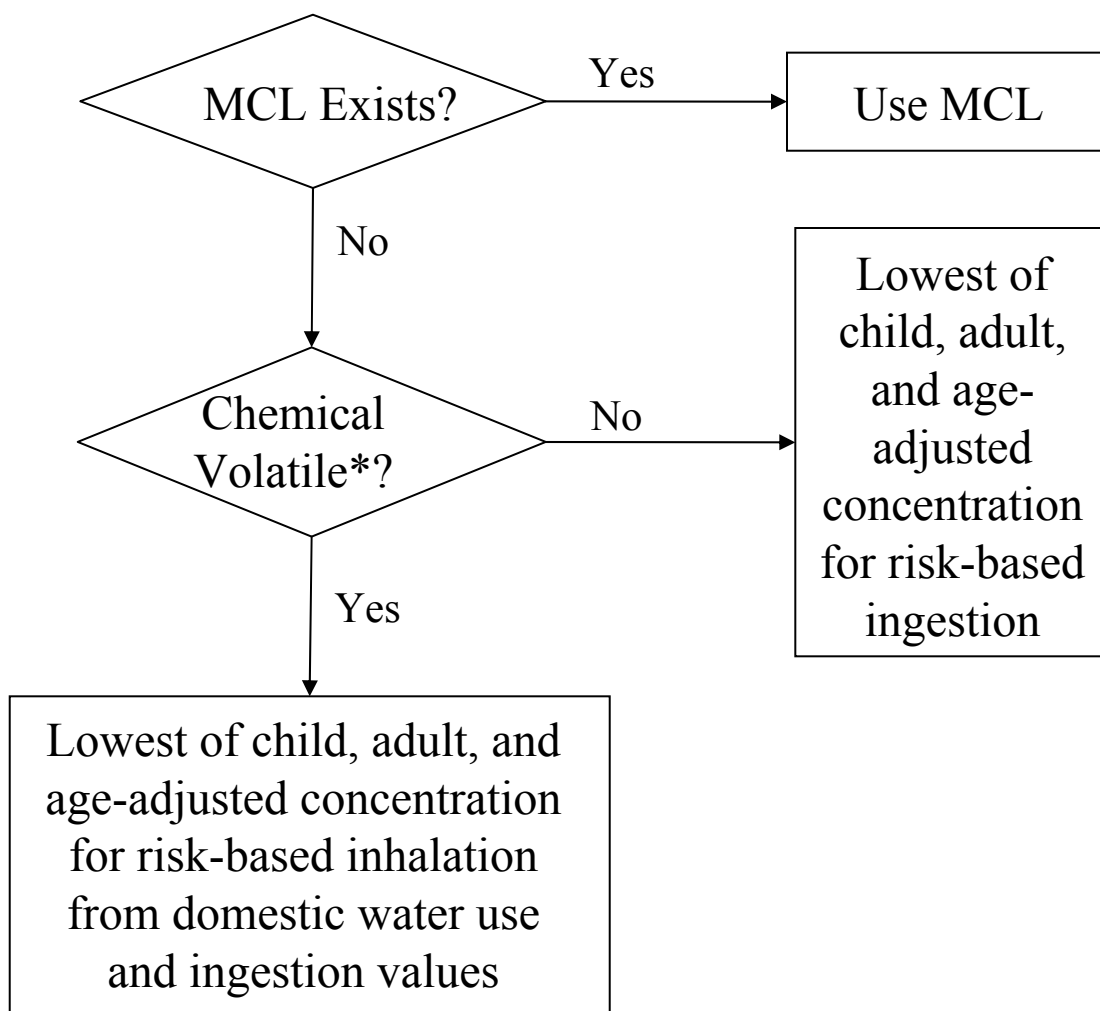
\* These parameters not used for DTL or Tier 1 RBTL caculations, but may be required for Tier 2 SSTLs.



**NOTE:**

1. In this chart, “use” refers to domestic consumption.
2. The analysis embodied in the chart is performed for each groundwater zone of interest. The conclusion of the analysis (the groundwater use pathway is either carried forward for additional consideration, or no further evaluation of the pathway is required) applies to the individual groundwater zone under analysis. Different conclusions may apply to different groundwater zones at a given site.
3. The attributes of an AUL must be sufficient to “eliminate reasonable probability of future use”, and, by that, allow a conclusion that “no further evaluation of groundwater use pathway required.”

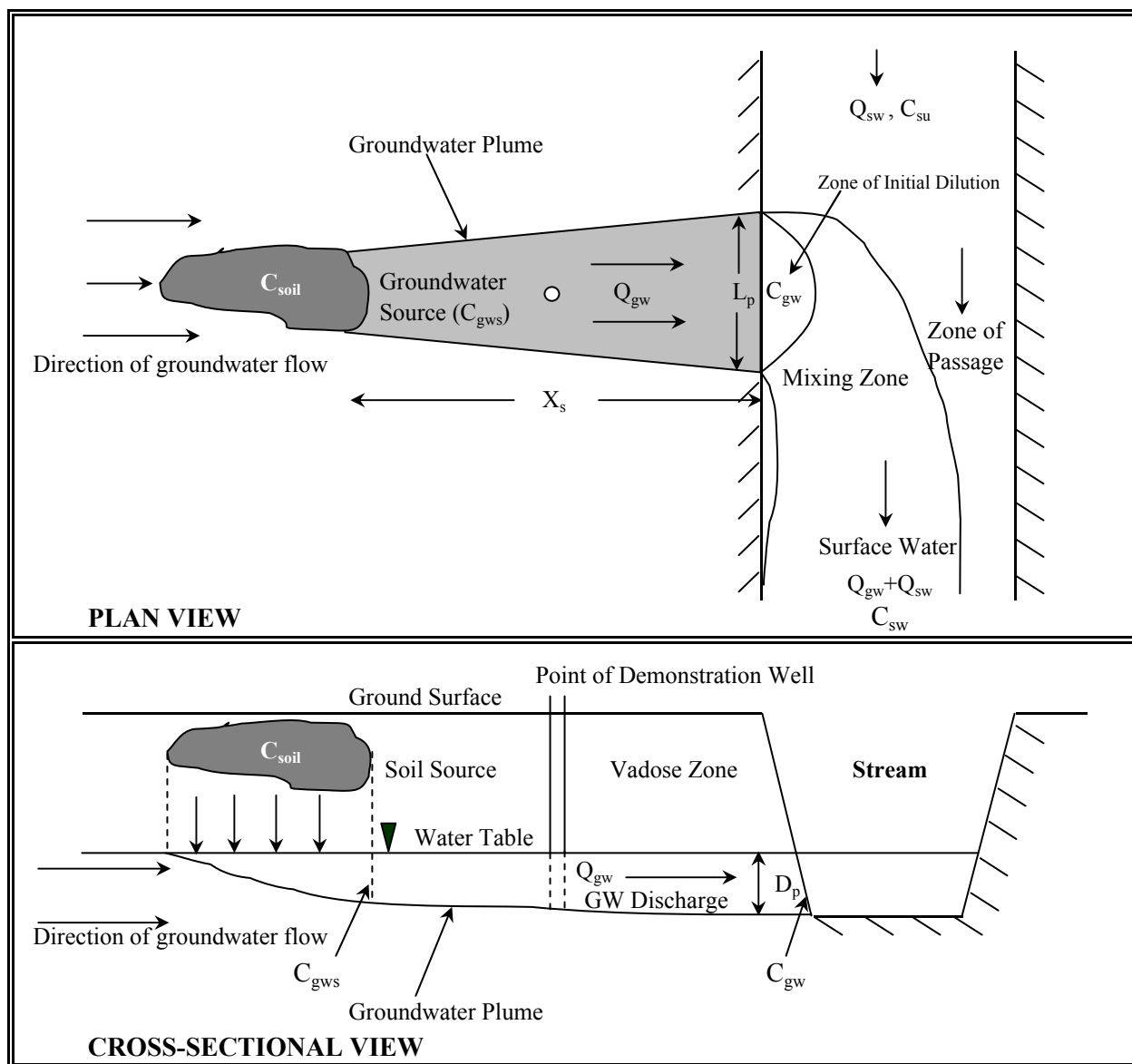
**Figure E-1. Conceptual Site Model for Domestic Consumption of Groundwater Exposure Pathway Analysis**



**MCL:** Maximum contaminant level

\* Chemical is volatile if  $MW < 200$  and  $H$  (dimensionless)  $> 4.2 \times 10^{-4}$ .

**Figure E-2. Determination of Groundwater Target Concentration at POE**



**Figure E-3. Schematic of Leachate Migration from the Soil to a Stream**

**Explanation of Symbols**

$Q_{sw}$  = Stream flow upstream of the point of groundwater discharge [ft<sup>3</sup>/day]

$C_{su}$  = Concentration upstream of the groundwater discharge [mg/L]

$Q_{gw}$  = Impacted groundwater discharge into the stream [ft<sup>3</sup>/day]

$C_{sw}$  = Allowable downstream concentration, i.e., specific water quality criteria to be met beyond the mixing [mg/L]

$C_{gw}$  = Allowable concentration in the groundwater discharge to the stream [mg/L]

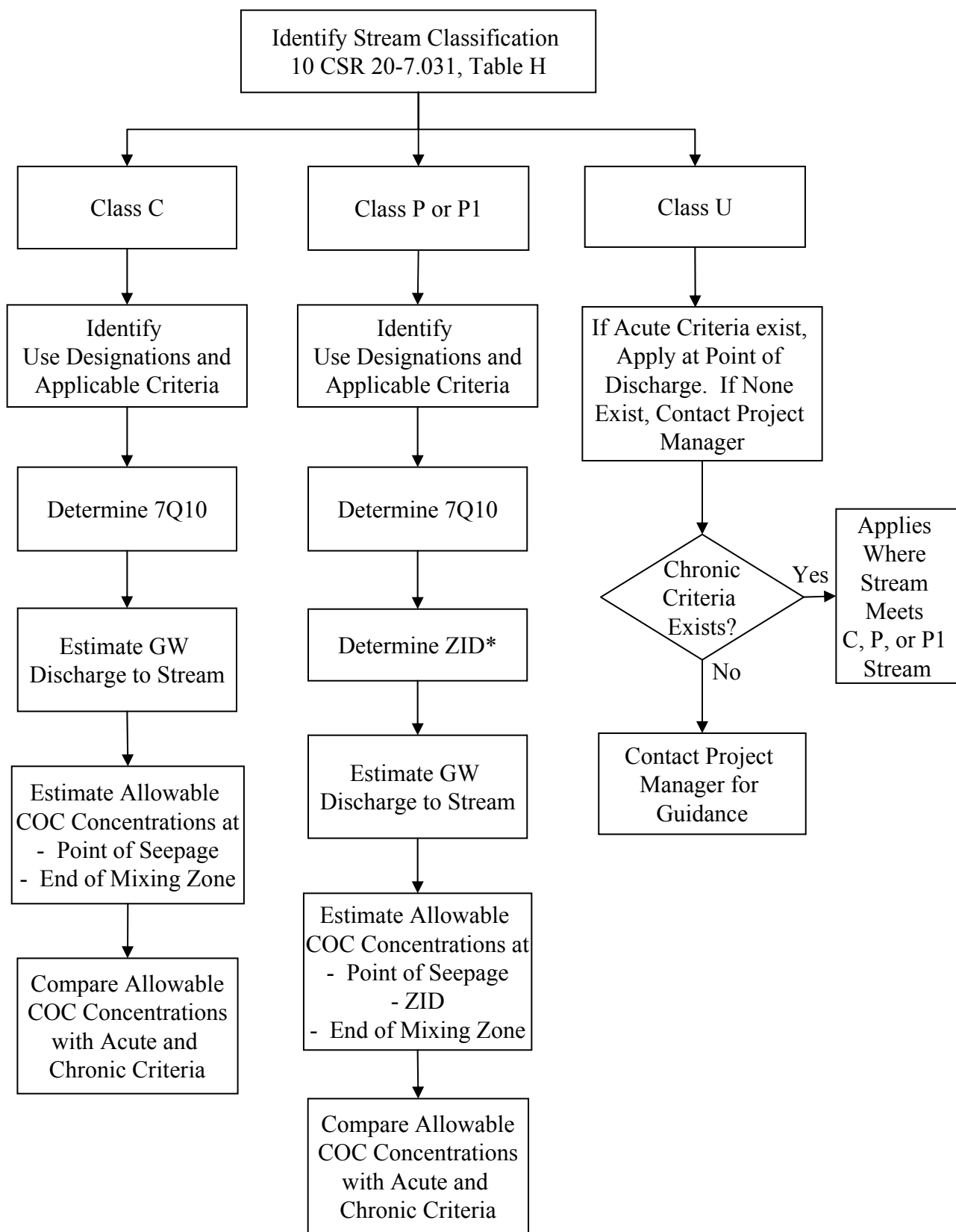
$C_{gws}$  = Allowable concentration in the groundwater at the edge of the soil source [mg/L]

$C_{soil}$  = Allowable soil concentration at the source [mg/kg]

$L_p$  = Width of groundwater plume discharging to the stream [ft]

$D_p$  = Thickness of groundwater plume discharging to the stream [ft]

$X_s$  = Distance from the downgradient edge of the groundwater source to the stream [ft]



\* ZID: Zone of Initial Dilution

**Figure E-4. Procedure for Protection of Stream Body**

**APPENDIX F**  
**ECOLOGICAL RISK ASSESSMENT CHECKLISTS**

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**Ecological Risk Assessment  
Screening Checklist for Potential Receptors and Habitat  
Level 1, Checklist A**

1. Is the boundary of the contaminated area less than ½ mile to a surface water body (stream, river, pond, lake, etc.)?
2. Are wetlands (as defined by the 1987 Corps of Engineers' Delineation Manual) on or adjacent to the site?
3. Are contaminated soils uncovered or otherwise accessible to ecological receptors and the elements?
4. Are there karstic features (see Ecological Risk Assessment Figure #2 for definition) on or within ½ mile of the boundary of the contaminated area?

Note: A professional opinion may be necessary to make this determination. The Missouri Environmental Geology Atlas (MEGA), published recently by the Department of Natural Resources, Geological Survey and Resource Assessment Division (GSRAD), provides several state-wide, karst-related data sets, as well as others related to geology and hydrology, in a geographic information system format that can assist in this determination. MEGA, including software to view the data sets, may be obtained from GSRAD by calling (573) 368-2125.

5. Are there federal or state rare, threatened, or endangered species on or within ½ mile of the contaminated area? Note: The ½ mile criterion does not apply to situations where a hydrological connection exists between the site and karstic features. Contact the Missouri Department of Conservation for state-listed species and the U.S. Fish and Wildlife Service for federally listed species.
6. Are there one or more environmentally sensitive areas (see Ecological Risk Assessment Figure #1 for definition) at or within ½ mile of the contaminated area?
7. Are commercially or recreationally important species (fauna or flora) on or within ½ mile of the contaminated area?

If the answer is "Yes" to any of the above questions, then complete Ecological Risk Assessment Checklist for Potential Exposure Pathways, Checklist B.

**Ecological Risk Assessment  
Screening Checklist for Potential Receptors and Habitat  
Level 1, Checklist B**

- 1.a.) Can contaminants associated with the site leach, dissolve, or otherwise migrate to groundwater?
- 1.b.) Are contaminants associated with the site mobile in groundwater?
- 1.c.) Does groundwater from the site discharge to ecological receptor habitat?

**Question 1:** Could contaminants associated with the site reach ecological receptors via groundwater?

- 2.a.) Is Non-Aqueous Phase Liquid (NAPL) present at the site?
- 2.b.) Is NAPL migrating?
- 2.c.) Could NAPL discharge occur where ecological receptors are found?

**Question 2:** Could contaminants from the site reach ecological receptors via migration of NAPL?

- 3.a.) Are contaminants present in surface soils?
- 3.b.) Can contaminants be leached from or be transported by erosion of surface soils?

**Question 3:** Could contaminants reach ecological receptors via erosional transport of contaminated soils or via precipitation runoff?

- 4.a.) Are contaminants present in surface soil or on the surface of the ground?
- 4.b.) Are potential ecological receptors on the site?

**Question 4:** Could contaminants reach ecological receptors via direct contact?

- 5.a.) Are contaminants present on the site volatile?
- 5.b.) Could contaminants on the site be transported in air as dust or particulate matter?

**Question 5:** Could contaminants reach ecological receptors via inhalation of volatilized contaminants or contaminants adhered to dust in ambient air or in subsurface burrows?

- 6.a.) Are contaminants present in surface and shallow subsurface soils or on the surface of the ground?
- 6.b.) Are contaminants found in soil on the site taken up by plants growing on the site?
- 6.c.) Do potential ecological receptors on or near the site feed on plants (e.g., grasses, shrubs, forbs, trees, etc.) found on the site?
- 6.d.) Do contaminants found on the site bioaccumulate?

**Question 6:** Could contaminants reach ecological receptors via direct ingestion of soil, plants, animals or contaminants?

- 7.a.) Are there karstic features (see Ecological Risk Assessment Figure #2 for definition) on or within ½ mile of the contaminated area?
- 7.b.) Is there a hydrogeological connection between the site and karstic features such as seeps, springs, streams or other surface water bodies?



**Question 7:** Could contaminants reach ecological receptors via transport through a karst system?

Note: ~~Answers to questions 7b and 7 must be supported by a statement from a Registered Geologist or Professional Engineer with geology practice. A professional opinion may be necessary to answer 7.a, 7.b, and Question 7.~~ –The Missouri Environmental Geology Atlas (MEGA), published recently by the Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division (GSRAD), provides several state-wide, karst-related data sets, as well as others related to geology and hydrology, in a geographic information system format, that can assist in answering these questions. MEGA, including software to view the data sets, can be obtained from GSRAD by calling (573) 368-2125. The determination of proximity to karst features/topography under questions 7b and 7 of Checklist B does not always require a field determination. However, in some cases, a field determination may be appropriate.

If the answer to one or more of the seven above questions is “Yes”, the department may require further assessment to determine whether the site poses an unacceptable risk to ecological receptors.

## **Ecological Risk Assessment**

### **Figure #1: Environmentally Sensitive Areas**

An Environmentally Sensitive Area is of special significance due to its flora or fauna, the sensitive nature of its natural features, historical considerations, or other reasons associated with the environment.

Examples of environmentally sensitive areas include, but are not limited to, the following:

- National and state parks,
- Designated and proposed federal and state wilderness and natural areas,
- Endangered, rare, and threatened species habitat as designated by the U.S. Department of the Interior or the Missouri Department of Conservation,
- National monuments,
- National and state historic sites,
- National and state lakeshore and river recreational areas,
- Federal or state designated scenic or wild rivers,
- Habitat of federal or state designated or proposed endangered, rare, or threatened species, and species under review as to their endangered, rare, or threatened status,
- National and state preserves and forests,
- National and state wildlife refuges,
- Critical fish and shellfish spawning areas,
- Critical migratory pathways and feeding areas for anadromous fish species within river reaches or areas in lakes where such species spend extended periods of time,
- Terrestrial areas used for breeding by large or dense aggregations of faunal species,
- State lands designated by the Missouri Department of Conservation for wildlife or game management,
- Wetlands as defined by the 1987 Corps of Engineers Delineation Manual and
- Outstanding state resource waters as designated by the Missouri Clean Water Commission.

## **Ecological Risk Assessment**

### **Figure #2: Karst Features**

Karst: A distinctive set of geomorphic landforms resulting from the development of extensive subsurface solution channels and caves in carbonate rocks (Boulding, 1995).

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**APPENDIX G**

**A METHOD FOR DETERMINING IF A WATER BEARING UNIT  
SHOULD BE CONSIDERED AN AQUIFER**

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**Geological Survey and Resource Assessment Division  
Department of Natural Resources  
January, 2004**

## **A METHOD FOR DETERMINING IF A WATER BEARING UNIT SHOULD BE CONSIDERED AN AQUIFER**

Several criteria must be met for a water-bearing zone to be considered a potentially usable aquifer. First, the water quality must be such that consuming the water does not pose an immediate or long-term risk to human health. Second, the water-bearing materials must yield at least enough water to serve a useful purpose. Realistically, if the water-bearing materials cannot adequately supply a single household, then it is doubtful if they would be considered an aquifer. Two factors controlling the volume of groundwater that can be produced from water-bearing materials are the hydraulic conductivity and the saturated thickness of the potential aquifer. It is necessary for both of these factors to be considered. The greater the hydraulic conductivity of the water-bearing materials, the greater the yield potential. However, a thick sequence of low hydraulic conductivity materials may actually yield more water than a thinner unit having a much higher hydraulic conductivity.

The technique described below was developed to aid in determining if a water-bearing unit should be considered an aquifer. A series of calculations were made based on several assumptions. It was assumed that to be considered a viable water supply, a well would need to be able to produce a minimum of 0.25 gallons of water per minute (360 gallons per day) for a period of 10 days. The calculated drawdown at the well at the end of this period could not exceed one-third of the saturated thickness of the water-bearing unit. A storage coefficient of 0.001 was assumed. The well was assumed to have an efficiency of 100 percent. The Theis nonequilibrium well equation (a.k.a., nonleaky artesian formula) was used to calculate the aquifer transmissivity necessary to meet these parameters for aquifer thickness between 10 to 200 feet. Hydraulic conductivity values were determined by dividing the calculated transmissivity values by the full saturated thickness.

The calculated hydraulic conductivity values were plotted against the saturated thickness of the aquifer (see graph on page G-4). The data plotted as a power function. A curve-fitting program was applied to derive the following empirical equation:

$$K = b^{-2.04} \times 1447 \quad (1)$$

where,

- K = hydraulic conductivity (gpd/ft<sup>2</sup>), and
- b = aquifer saturated thickness (feet).

If the saturated thickness of the water-bearing zone under consideration is known, then the equation can be used to calculate the average hydraulic conductivity that will be necessary to meet the minimum aquifer requirements listed above. Conversely, if a representative value for the hydraulic conductivity has been determined, then the equation can be re-written to determine the minimum saturated thickness that will be needed to meet the minimum aquifer requirements shown above. That equation is:

$$b = K^{-0.496} \times 35.33 \quad (2)$$

Hydraulic conductivity values in units of gpd/ft<sup>2</sup> and ft/day are commonly used in the water supply field but are not widely used in environmental work where hydraulic conductivity values are typically reported in units of cm/sec. To convert a hydraulic conductivity value measured in gpd/ft<sup>2</sup> to cm/sec, multiply it by  $7.75 \times 10^{-5}$ .

Below are two examples:

### **EXAMPLE 1**

Test drilling and slug tests show that a water-saturated sandy silt has a hydraulic conductivity of  $2.5 \times 10^{-4}$  cm/sec. A thick clay unit underlies the materials, and the saturated thickness of the sandy silt unit is 23 feet. Does it meet the criteria necessary to be considered a potentially usable aquifer?

We will assume the water quality meets minimum requirements for potability. A hydraulic conductivity of  $2.5 \times 10^{-4}$  cm/sec is equal to 3.2 gpd/ft. With this hydraulic conductivity, the minimum saturated thickness needed is from Equation (2):

$$3.2^{-0.496} \times 35.33 \text{ or } 19.8 \text{ feet}$$

Based on the above, the zone would be considered a potentially usable aquifer.

### **EXAMPLE 2**

Test drilling below a site shows 80 feet of fairly uniform sandy clay till. What would be the minimum average hydraulic conductivity necessary for this material to comprise an aquifer?

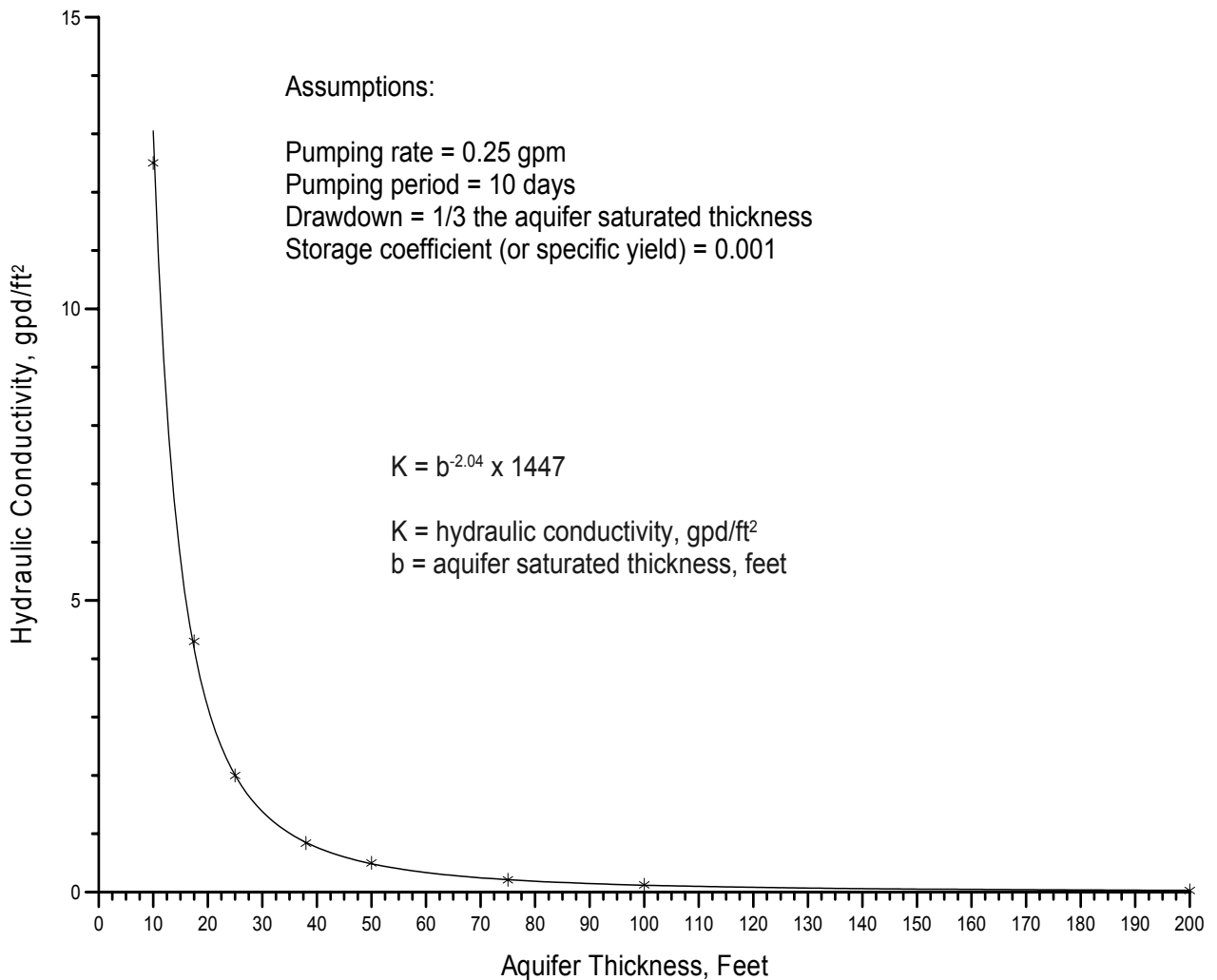
$$K = 80^{-2.04} \times 1447$$

$$K = 0.19 \text{ gpd/ft}^2 \text{ or } 1.47 \times 10^{-5} \text{ cm/sec}$$

Based on this technique, 80 feet of sandy clay till having an average hydraulic conductivity of  $1.47 \times 10^{-5}$  cm/sec (or 0.19 gpd/ft<sup>2</sup>) would be considered a usable aquifer.

Changing any of the aquifer parameters and yield assumptions listed above would, of course, change equations 1 and 2 above. Some argument could be made as to the assumed pumping period of 10 days. Perhaps a pumping period of 1 day might seem more appropriate. However, it must be remembered that the Theis nonequilibrium equation assumes confined (artesian) conditions. For it to be entirely valid, the saturated thickness of the aquifer must remain essentially unchanged. The drawdown must not lower the potentiometric surface an appreciable distance below the top of the aquifer. Most shallow aquifers that will be considered under this rule will likely be unconfined. As drawdown occurs in an unconfined aquifer, the saturated thickness of the aquifer within the drawdown cone decreases. Thus, the transmissivity (which is the product of

the hydraulic conductivity and the saturated thickness) also decreases. Reducing the saturated thickness of an unconfined aquifer by one-third will reduce its transmissivity proportionally. Because of this, the assumed drawdown of one-third the aquifer thickness is probably optimistic for an unconfined aquifer. The actual drawdown will be somewhat larger if the well is actually pumped 0.25 gpm for 10 days. If a shorter pumping period is selected for consideration, then the allowable drawdown should be changed from one-third the saturated thickness of the aquifer to a more conservative value, such as 10 percent of the saturated thickness of the aquifer.



**APPENDIX H**  
**MEASUREMENT OF SOIL VAPOR LEVELS**

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(Under Development)



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**APPENDIX I**

**FLEXIBILITY IN CALCULATION OF TIER 2 AND TIER 3  
SITE-SPECIFIC TARGET LEVELS**

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For the MRBCA process, the acceptable risk levels are as follows:

Carcinogenic Risk

- The total risk for each chemical, which is the sum of risk for all complete exposure pathways for each chemical, must not exceed  $1 \times 10^{-5}$ .
- The cumulative site-wide risk (sum of risk for all chemicals and all complete exposure pathways) must not exceed  $1 \times 10^{-4}$ .

Non-carcinogenic Risk

- The hazard index for each chemical, which is the sum of hazard quotients for all complete exposure pathways for each chemical (the total risk) must not exceed 1.0.
- The site-wide hazard index, which is the sum of hazard quotients for all chemicals and all complete exposure pathways, must not exceed 1.0.

Note if the hazard index exceeds 1.0, the hazard index corresponding to a specific toxicological end point may be calculated by a qualified toxicologist. In this case, the specific hazard indices for each toxicological end point must be less than unity (1.0).

If any of these acceptable risk levels are exceeded, a risk management plan is necessary to reduce the concentrations to acceptable levels. These acceptable risk criteria can be satisfied in a number of different ways that provide considerable flexibility to the remediating party. Due to this flexibility, the remediating party can select the risk management plan that is optimal for the site-specific conditions.

To illustrate the above flexibility, an example is presented below.

Consider the following site that has four chemicals and three complete routes of exposure. Exhibit 1 presents the representative concentrations for each chemical and each route of exposure used to estimate the risk presented in Exhibit 2.

**Exhibit 1. Representative Concentrations for Each Chemical and  
Each Route of Exposure**

Chemicals	ROE 1 (mg/kg)	ROE 2 (mg/kg)	ROE 3 (mg/kg)
Chemical 1	1.5	1.0	1.0
Chemical 2	0.5	0.75	1.0
Chemical 3	0.25	0.5	0.5
Chemical 4	0.20	0.25	5.0

## Exhibit 2. Risk Calculated Using Representative Concentrations in Exhibit 1

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	$1.1 \times 10^{-5}$	$4.0 \times 10^{-6}$	$5.0 \times 10^{-6}$	$2.0 \times 10^{-5}$
Chemical 2	$5.0 \times 10^{-6}$	$7.5 \times 10^{-6}$	$2.0 \times 10^{-6}$	$1.45 \times 10^{-5}$
Chemical 3	$5.0 \times 10^{-6}$	$2.0 \times 10^{-6}$	$5.0 \times 10^{-7}$	$7.5 \times 10^{-6}$
Chemical 4	$9.8 \times 10^{-5}$	$8.9 \times 10^{-5}$	$7.0 \times 10^{-6}$	$1.33 \times 10^{-4}$
<b>Cumulative Site-Wide Risk</b>				<b><math>1.75 \times 10^{-4}</math></b>

Note that the following acceptable risks are exceeded:

- Total risk for chemical 1,
- Total risk for chemical 2,
- Total risk for chemical 4, and
- Cumulative site-wide risk.

To meet the acceptable risk criteria, the remediating party may select any one of the following three risk management plans.

### Example 1

The concentration of each of the chemicals may be reduced by a factor of 2.0. This will result in total risk of each below  $1.0 \times 10^{-5}$  and cumulative site-wide risk  $1.0 \times 10^{-4}$ . For this case the resulting cleanup levels and risks would be:

Chemicals	ROE 1 (mg/kg)	ROE 2 (mg/kg)	ROE 3 (mg/kg)
Chemical 1	0.75	0.5	0.5
Chemical 2	0.25	0.375	0.5
Chemical 3	0.125	0.25	0.25
Chemical 4	0.1	0.125	2.5

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	$5.5 \times 10^{-6}$	$2.0 \times 10^{-6}$	$2.5 \times 10^{-6}$	$1.0 \times 10^{-5}$
Chemical 2	$2.5 \times 10^{-6}$	$3.75 \times 10^{-6}$	$1.0 \times 10^{-6}$	$7.25 \times 10^{-6}$
Chemical 3	$2.5 \times 10^{-6}$	$1.0 \times 10^{-6}$	$2.5 \times 10^{-7}$	$3.75 \times 10^{-6}$
Chemical 4	$4.9 \times 10^{-5}$	$4.45 \times 10^{-5}$	$3.5 \times 10^{-6}$	$6.65 \times 10^{-5}$
<b>Cumulative Site-Wide Risk</b>				<b><math>8.9 \times 10^{-5}</math></b>

### **Example 2**

Activity and Use Limitations (AULs) may be used to eliminate two of the pathways, resulting in the following risks:

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	Eliminated Pathway	Eliminated Pathway	$5.0 \times 10^{-6}$	$5.0 \times 10^{-6}$
Chemical 2			$2.0 \times 10^{-6}$	$2.0 \times 10^{-6}$
Chemical 3			$5.0 \times 10^{-7}$	$5.0 \times 10^{-7}$
Chemical 4			$7.0 \times 10^{-6}$	$7.0 \times 10^{-6}$
Cumulative Risk				$1.45 \times 10^{-5}$

In the above, both the total risk for each chemical and the cumulative site-wide risk are acceptable.

### **Example 3**

In this case the concentrations of the chemicals are reduced by varying factors. For example we could reduce the concentration of chemicals 1 to 3 by a factor of 2 and reduce concentration of chemical 4 by a factor of 14. This would result in the following cleanup levels and risk:

Chemicals	ROE 1 (mg/kg)	ROE 2 (mg/kg)	ROE 3 (mg/kg)
Chemical 1	0.75	0.5	0.5
Chemical 2	0.25	0.375	0.5
Chemical 3	0.125	0.25	0.25
Chemical 4	0.1	0.125	2.5

Chemicals	ROE 1	ROE 2	ROE 3	Total
Chemical 1	$5.5 \times 10^{-6}$	$2.0 \times 10^{-6}$	$2.5 \times 10^{-6}$	$1.0 \times 10^{-5}$
Chemical 2	$2.5 \times 10^{-6}$	$3.75 \times 10^{-6}$	$1.0 \times 10^{-6}$	$7.25 \times 10^{-6}$
Chemical 3	$2.5 \times 10^{-6}$	$1.0 \times 10^{-6}$	$2.5 \times 10^{-7}$	$3.75 \times 10^{-6}$
Chemical 4	$7.0 \times 10^{-6}$	$6.36 \times 10^{-6}$	$5.0 \times 10^{-7}$	$1.38 \times 10^{-6}$
<b>Cumulative Risk</b>				<b><math>2.23 \times 10^{-5}</math></b>

For this case the cumulative risk at the site is equal to  $2.23 \times 10^{-5}$  and it is therefore below acceptable risk levels.

The above represents a case where a selected remedial technology reduces the site-specific concentrations by different amounts. For example, soil vapor extraction,

depending on the volatility of chemical, would reduce the concentrations of the volatile chemicals by different amounts.

**APPENDIX J**

**APPENDIX TO SECTION 11 LONG-TERM STEWARDSHIP FOR  
RISK-BASED REMEDIATION SITES**

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<b>APPENDIX J-1.....</b>	<b>J-2</b>
<b>MODEL DECLARATION OF RESTRICTIVE COVENANT AND GRANT OF ACCESS</b>	
<b>APPENDIX J-2.....</b>	<b>J-11</b>
<b>MODEL ORDINANCE FOR USE IN LONG-TERM STEWARDSHIP OF CONTAMINATED SITES WHEN GROUNDWATER CONTAMINATION IS PRESENT</b>	
<b>APPENDIX J-3.....</b>	<b>J-14</b>
<b>INSTITUTIONAL CONTROL CONTRACT</b>	
<b>APPENDIX J-4.....</b>	<b>J-17</b>
<b>MODEL NOTIFICATION LETTER</b>	

**APPENDIX J-1**  
**MODEL DECLARATION OF RESTRICTIVE COVENANT**  
**AND GRANT OF ACCESS**

The following Model Restrictive Covenant and Grant of Access model document is to be used when response activities have been approved by MDNR and should not be used if MDNR has not approved the response activities. The final format of this document should comply with appropriate state and local recording requirements to facilitate recordation by the County Recorder of Deeds.

**MODEL DECLARATION OF RESTRICTIVE COVENANT**  
**AND GRANT OF ACCESS**

This Restrictive Covenant and Grant of Access has been recorded with the \_\_\_\_\_ County Recorder of Deeds for the purpose of protecting public health, safety, and welfare, and the environment by prohibiting or restricting activities that could result in unacceptable exposure to environmental contamination present at the property located at [insert location of property in city and county] and legally described in Exhibit A hereto (“Property”). Any portion of the Property that is not subject to activity or land use restrictions is identified and distinguished by legal description and survey in Exhibit A-1.

Pursuant to an Agreement between the department and the Remediating Party, the Remediating Party implemented certain response activities at the Property approved by MDNR. These activities are briefly described herein and fully described in documents available from MDNR, a political subdivision of the State of Missouri, having a mailing address of P.O. Box 176, Jefferson City, Missouri 65102.

Missouri law requires the recording of this Restrictive Covenant and Grant of Access with the \_\_\_\_\_ County Recorder of Deeds in order to:

[Insert appropriate description of purpose from “Model Paragraphs for Use in Restrictive Covenant,” part 1, Purpose(s) of Restrictive Covenant. Note: the Model Paragraphs may be modified as appropriate for the Property.]

**Summary of Response Activities.**

**[Insert a paragraph that briefly describes the response activities which have been conducted i.e. soil removal to remediate xyz contaminants in whatever area of the site; placement of engineered cap; remediation of groundwater; asbestos or lead paint abatement, etc., and how the response activities address unacceptable risk for all relevant pathways that require restrictions]**

**MDNR recommends that prospective purchasers or users of the Property**

undertake appropriate due diligence prior to acquiring or using this Property.

**NOW THEREFORE,**

Restrictions and Conditions

**(insert name of property owner), (insert mailing address of owner)**  
(hereinafter referred to as the “Owner”), hereby declares and covenants that the Property shall be subject to the following restrictions and conditions:

1. **Restrictions Applicable to the Property.** The following restrictions and duties apply to the property and shall be the responsibility of the owner:

[insert appropriate restrictions based on the attached “Model Paragraphs for Use in Restrictive Covenants,” part 2, “Restrictions.” The Model Paragraphs may be modified as appropriate for each Property in negotiations with MDNR.]

[IF USER DESIRES ANY USAGES TO BE SPECIFICALLY ALLOWED, INCLUDE HERE USING A STATEMENT: “THESE RESTRICTIONS DO NOT PREVENT . . .”]

[Note: mandatory activities to ensure site integrity should be added here.]

[Note: Maintenance and inspection responsibilities should be set out either here or in the Risk Management Plan.]

[Note: Any limitations on alteration of the Property should be set out here.]

2. **Contaminated Soil Management.** The Owner shall manage all soils, media and/or debris located on the Property in accordance with the applicable requirements of Missouri and federal law.

3. **Grant of Access to the department.** Owner hereby grants and conveys to the department, its agents, contractors, and employees, and to any person performing pollution remediation activities under the direction thereof, access at reasonable times to the Property to determine and monitor compliance with the Risk Management Plan and perform such investigations and actions as the department deems necessary to ensure that use, occupancy, and activities of and at the Property are consistent with this Restrictive Covenant; ensure that any remediation implemented complies with state law; perform any additional investigations or remediation deemed necessary to maintain compliance with the approved Risk Management Plan; and ensure the structural integrity and continued effectiveness of any engineering controls (if appropriate) described in this Restrictive Covenant and Grant of Access.

4. **Notice to Lessees and Other Holders of Interest in the Property.** Owner, or



any future holder of any interest in the Property, shall cause any lease, grant, or other transfer of any interest in the Property to include a provision expressly requiring the lessee or transferee to comply with this Restrictive Covenant and Grant of Access. The failure to include such provision shall not affect the validity or applicability to the Property of this Restrictive Covenant and Grant of Access.

5. **Enforceability of Restrictions; Persons Entitled to Enforce Restrictions.** This Restrictive Covenant shall run with the land and shall be binding on the Owner, future Owners, heirs, successors, lessees, or assigns and their authorized agents, employees or persons acting under their direction or control. This Restrictive Covenant shall be enforceable in an appropriate Court by Owner and/or by the department, their successors, transferees, and assigns. Owner agrees that the restrictions are enforceable, and agrees not to challenge the appropriate circuit court's jurisdiction. The State of Missouri, through MDNR, may enforce the restrictions set forth in the Restrictive Covenant by legal action in a court of competent jurisdiction.
6. **Written Notice of Property Conveyance Required.** The Owner shall provide written notice to the Director of the department, of the intent to transfer an interest in the Property not less than 14 days prior to the expected date of transfer. This notice shall include the name and business address of the transferee and the expected date of transfer.
7. **Property Conveyance – Continuance of Provisions.** The Owner shall not convey any title, access, or other interest in the Property without providing notice to those acquiring the interest of the continued implementation, operation, and maintenance of any remedial action that has been implemented on the Property and requiring along with the interest the prevention of the releases and exposures described above.
8. **Severability.** If any provision of this Restrictive Covenant and Grant of Access is held invalid by any Court of competent jurisdiction, invalidity of any such provision shall not affect the validity of any other provisions hereof. Also, such provisions shall continue unimpaired in full force and effect.
9. **Amending, Modifying, or Rescinding the Restrictive Covenant.** This Restrictive Covenant and Grant of Access shall not be amended, modified or terminated except by a written instrument executed by and between the Owner at the time of the proposed amendment, modification, or termination and the department. Within five (5) days of executing an amendment, modification, or termination of this Restrictive Covenant and Grant of Access, the Owner shall record such amendment, modification, or termination, on the appropriate form provided by the department, with the \_\_\_\_\_ County Recorder of Deeds, and within five (5) days thereafter, the Owner shall provide a true copy of the recorded amendment, modification, or termination to the department.

10. **Disputes.** Any disputes regarding provisions of this covenant that cannot be resolved by the department and the property owner will be addressed pursuant to the [rule].
11. **Institutional Control Contract.** The department's Hazardous Waste Program requires that owners of property for which a Restrictive Covenant and Grant of Access is required enter into an Institutional Control Contract with the department. Said Contract is attached hereto as Exhibit B and by this reference made a part hereof.
12. **Authority to Execute Restrictive Covenant.** The undersigned person executing this Restrictive Covenant and Grant of Access is the Owner, or has the express written permission of the Owner and represents and certifies that he or she is duly authorized and has been empowered to execute and deliver this Restrictive Covenant and Grant of Access.

## SIGNATURES

The undersigned property owner or person executing this Restrictive Covenant and Grant of Access on behalf of the Owner represents and certifies that they are truly authorized and have been fully empowered to execute and deliver this Restrictive Covenant and Grant of Access.

STATE OF MISSOURI       )  
                                      )  
COUNTY OF                )       SS

Property owner(s) or authorized representative(s) thereof

Type or Print : Signature \_\_\_\_\_ Date:

Type or Print: Signature \_\_\_\_\_ Date:

**IN WITNESS WHEREOF**, the Owner(s) or Owner's authorized representative(s) of the above-described Property has caused this Restrictive Covenant and Grant of Access to be executed on this \_\_\_\_\_ day of \_\_\_\_\_, 20\_\_\_\_. Signed in the presence of Property Owner/Authorized Representative subscribed and acknowledged.

Subscribed and acknowledged before me this \_\_\_\_ day of \_\_\_\_\_, 20 \_\_\_\_.

Notary Public

My commission expires \_\_\_\_\_.

## MODEL PARAGRAPHS FOR USE IN RESTRICTIVE COVENANT

### 1. Purpose(s) of Restrictive Covenant

Insert one or more of the following as applicable at section 1 of the restrictive covenant. Specific language in these model paragraphs may be negotiated with MDNR for each Property.

- A. That the Property is used in a manner consistent with the risk assessment and resulting risk-based cleanup standards for the Property, which assessment has either been prepared or approved by the Missouri Department of Health and Senior Services.
- B. That groundwater at the Property is not used [at all or for domestic uses such as drinking or bathing].
- C. That humans are not exposed to soils at the Property contaminated with substances in concentrations exceeding the levels established in the Risk Management Plan for the Property.
- D. That storm water or water of other origin does not infiltrate soils at the Property contaminated with substances in concentrations exceeding the pollutant mobility criteria established by the department.
- E. That Buildings are not constructed over soils [or ground water] at the Property contaminated with substances in concentrations exceeding the volatilization criteria established by the department [or that pose a risk of forming dangerous levels of vapors inside such buildings] (defined with plat).
- F. That the engineered control(s) described herein are not disturbed and are properly maintained to prevent human and ecological exposure to soils at the Property polluted with substances in concentrations exceeding the levels established in the cleanup plan or risk assessment for the Property.
- G. Other (as circumstances require).

### 2. Restrictions

Specific language in these model paragraphs may be negotiated with MDNR for each Property. Restrictions fall into several categories including land use, groundwater, disturbance, and construction. Depending on site-specific conditions, restrictions other than those listed here may be appropriate, and will be negotiated between the property owner and the department. Be specific in describing uses from zoning ordinances.

USE RESTRICTIONS:

- A. **Nonresidential Use or Construction Worker Use** (reference specific zoning ordinances): The Property currently meets the department standards for restricted nonresidential or construction worker use and, based on reports on file at the department offices in Jefferson City, Missouri, the

contaminants present pose no significant present or future risk to human health or the environment based on restricted use of the Property. No further response action for the Property is required by the department as long as the Property is not to be used for residential or other purposes constituting unrestricted use. The Property shall not be used for purposes other than nonresidential or construction worker uses. If any person desires in the future to use the Property for residential or other purposes constituting unrestricted use, the department must be notified 120 days in advance and further analyses and, as necessary, response actions will be necessary prior to such use. The Property may not be used in a manner that conflicts with this limitation.

- B. Nonresidential Use With Engineered Controls** (reference specific zoning ordinances): The Property currently meets the department standards for restricted nonresidential or construction worker uses and, based on reports on file at the department offices in Jefferson City, Missouri, the contaminants present pose no significant present or future risk to human health or the environment based on restricted nonresidential or construction worker uses of the Property. No further response action for the Property is required by the department as long as the Property is not to be used for residential or other purposes constituting unrestricted use. The Property is protective for restricted commercial or industrial uses as long as the **(insert engineering or other physical controls in place)** is/are maintained to prevent exposure. The Property shall not be used for purposes other than nonresidential or construction worker uses. If any person desires in the future to use the Property for residential or other purposes constituting unrestricted use, the department must be notified 120 days in advance and further analyses and, as necessary, response actions will be necessary prior to such use. The Property may not be used in a manner that conflicts with this limitation.

#### GROUNDWATER RESTRICTIONS:

- C. No Drilling or Use of Groundwater:** The groundwater beneath the Property contains contaminants at concentrations exceeding applicable cleanup standards. The owner and operator of the Property shall prevent: use of and exposure to the groundwater; any artificial penetration of the groundwater-bearing unit(s) containing contaminants that could result in cross-contamination of clean groundwater-bearing units; installation of any new groundwater wells on the Property, except those used for investigative purposes; use of groundwater for drinking or other domestic purposes and the use of groundwater for purposes other than domestic purposes; release of groundwater to surface water bodies, whether such release is the result of human activities or is naturally occurring. Should a release of contaminated groundwater occur, the owner must take action to contain and properly dispose of such groundwater. [OPTIONAL IF NEEDED: Groundwater

beneath the Property shall be monitored by the owner in accordance with specific requirements of the department-approved monitoring plan unless or until the department approves any modifications].

- D. No Drilling or Use of Groundwater; Engineered Controls for Groundwater:** The groundwater beneath the Property contains contaminants identified in reports on file at the department offices in Jefferson City, Missouri at concentrations that exceed the cleanup standards of the department, and **(insert physical or engineering controls)** have been constructed in the area located on the map attached as “**Exhibit ( )**.” The physical or engineering controls must remain in place and effective in accordance with the department-approved **(insert name of plan)** unless or until the department approves any modifications. Additionally, the owner and operator of the Property must prevent: use of and exposure to the groundwater; any artificial penetration of the groundwater-bearing unit(s) containing contaminants which could result in cross-contamination of clean groundwater-bearing units; the installation of any new groundwater wells on the Property, except those used for investigative purposes; the use of groundwater for drinking or other domestic purposes and the use of groundwater for purposes other than domestic purposes; and release of groundwater to surface water bodies, whether such release is the result of anthropic activities or is naturally occurring. Should a release of contaminated groundwater occur, the owner must take action to contain and properly dispose of such groundwater. [Groundwater beneath the Property shall be monitored by the owner in accordance with specific requirements of the department-approved monitoring plan unless or until the department approves any modifications].

**DISTURBANCE RESTRICTIONS:**

- E. No Disturbance of Soil:** Soil at the Property contains contaminants, as identified in reports on file at the department offices in Jefferson City, Missouri, at concentrations exceeding the department’s cleanup standards for **(Nonresidential or Construction Worker Use)** use **[in the areas shown on the map at Exhibit ( ) attached hereto]**. Therefore, soil at the Property **[in the areas shown on the map at Exhibit ( ) attached hereto]** shall not be excavated or otherwise disturbed in any manner without the written permission of the department. Should the owner or operator desire to disturb soil at the Property **[in one or more of the areas shown on the map at Exhibit ( ) attached hereto]**, they shall request permission to do so from the department at least 30 days before the soil disturbance activities are to begin. Based on the potential hazards associated with the soil disturbance activities, the department may deny the request to disturb the soils or may require specific protective or remedial actions before allowing such soil disturbance activities to occur.

- F. Disturbance of Soil Permitted Under Approved Soil Management Plan:** Soil at the Property contains contaminants, as identified in reports on file at the department offices in Jefferson City, Missouri, at concentrations exceeding the department's cleanup standards for **(Nonresidential or Construction Worker Use)** use **[in the areas shown on the map at Exhibit ( ) attached hereto]**. Therefore, soil at the Property **[in the areas shown on the map at Exhibit ( ) attached hereto]** shall not be excavated or otherwise disturbed in any manner unless under the provisions of the department-approved Soil Management Plan attached hereto as Exhibit \_\_\_\_\_.

CONSTRUCTION RESTRICTIONS:

- G.** Soil at the Property contains contaminants, as identified in reports on file at the department offices in Jefferson City, Missouri, at concentrations exceeding the department's cleanup standards for **(Nonresidential or Construction Worker Use)** use **[in the areas shown on the map at Exhibit ( ) attached hereto]**. Therefore, no buildings may be constructed on the Property **[in the areas shown on the map at Exhibit ( ) attached hereto]** except with the written permission of the department. Should the owner or operator desire to construct a building on the Property **[in one or more of the areas shown on the map at Exhibit ( ) attached hereto]**, they shall request permission to do so from the department at least 30 days before construction is anticipated to begin. Based on the potential hazards associated with the construction activities, the department may deny the request to construct or may require specific protective or remedial actions before allowing such construction activities to occur.

**APPENDIX J-2**  
**MODEL ORDINANCE FOR USE IN LONG-TERM STEWARDSHIP OF**  
**CONTAMINATED SITES WHEN GROUNDWATER CONTAMINATION IS**  
**PRESENT**

Regulations setting forth procedures for determining risk-based remediation objectives may allow higher amounts of soil and/or groundwater contamination to remain in place where activity and use limitations (legal barriers to access) are established. Local ordinances prohibiting the use of groundwater for potable or other purposes and prohibiting the installation and use of new water supply wells are one type of control. Ordinances suitable for use as an effective control may serve as a part of a remediation plan, and they may demonstrate that contaminants of concern in soil and groundwater will meet applicable cleanup criteria. Ordinances also may be relied upon to exclude the groundwater ingestion exposure route from further consideration. Where there are no existing wells and where future uses of groundwater are prohibited, it is unnecessary to remediate contamination to levels based on domestic uses of groundwater.

To be recognized as part of a site remediation plan, an ordinance must provide a free-standing, self-contained enforceable legal barrier to contamination. It does not rely on any further action by local officials to be implemented, and those officials will be available for enforcement as necessary. The ordinance must effectively prohibit the installation and use of water wells.

Following is a model ordinance that satisfies the regulatory requirements for ordinances used to manage contaminants left in place above unrestricted use levels. Changes from this form may be allowed for specific local government conditions; however the basic requirements of the ordinance must be included and unencumbered. Local governments should assess their current and future water supply needs and resources before deciding whether the use of such ordinances is consistent with the long-range public water supply plan.



**ORDINANCE NUMBER \_\_\_\_\_**

**AN ORDINANCE PROHIBITING THE USE OF GROUNDWATER AS A  
POTABLE WATER SUPPLY BY THE INSTALLATION OR USE OF POTABLE  
WATER SUPPLY WELLS OR BY ANY OTHER METHOD**

WHEREAS, certain properties in the [City/County] of \_\_\_\_\_, Missouri have been used over a period of time for commercial/industrial purposes; and

WHEREAS, because of said use, concentrations of certain chemical constituents in the groundwater beneath the [City/County] may exceed groundwater quality standards for drinking water or other uses described in Missouri water quality standards 10 CSR 20-7.031 or other criteria established as risk-based remediation cleanup standards described in ?? CSR ??-???? [RBCA rule]; and

WHEREAS, the [City/County] of \_\_\_\_\_ desires to limit potential threats to human health, public welfare and the environment from groundwater contamination while facilitating the redevelopment and productive use of properties that are the source of said chemical constituents;

NOW, THEREFORE, BE IT ORDAINED BY THE [CITY COUNCIL/COUNTY COMMISSION] OF THE [CITY/COUNTY] OF \_\_\_\_\_, MISSOURI:

**Section One. Prohibitions.**

The use of groundwater as a potable water supply, cooling water or other uses is prohibited. The use or attempt to use groundwater from within the corporate limits of the [City/County] of \_\_\_\_\_ by the operation, installation or drilling of wells or by any other method is hereby prohibited. The [City/County] of \_\_\_\_\_ may operate existing points of withdrawal if authorized through a Memorandum of Understanding described in Section Four.

**Section Two. Penalties and Injunctive Relief.**

Any person violating the provisions of this ordinance shall be subject to a fine of up to \_\_\_\_\_ for each violation. Any person that violates this ordinance must close the well within thirty (30) days by methods specified in regulation by the state. The city will close any well that is not closed within thirty (30) days, and may recover the costs of completing the closure from the owner.

**Section Three. Definitions.**

" Person" is any individual, partnership, co-partnership, firm, company, limited liability company, corporation, association, joint stock company, trust, estate, political subdivision, or any other legal entity, or their legal representatives, agents or assigns.

**Section Four. Memorandum of Agreement.**

The [Mayor/Commission] of the [City/County] of \_\_\_\_\_ is hereby authorized and directed to enter into a Memorandum of Agreement with the Missouri Department of Natural Resources (department) for tracking remediated sites, notifying the department of changes to this ordinance, and taking certain precautions when siting public water supply wells.

Section Five. Repealer.

All ordinances or parts of ordinances in conflict with this ordinance are hereby repealed insofar as they are in conflict with this ordinance.

Section Six. Severability.

If any provision of this ordinance or its application to any person or under any circumstances is adjudged invalid, such adjudication shall not affect the validity of the ordinance as a whole or of any portion not adjudged invalid.

Section Seven. Effective date.

This ordinance shall be in full force and effect from and after its passage, approval and publication as required by law.

ADOPTED: \_\_\_\_\_  
(Date) (City Clerk)

APPROVED: \_\_\_\_\_  
(Date) (Mayor)

Officially published this \_\_\_\_\_ day of \_\_\_\_\_, 20\_\_\_\_.

### APPENDIX J-3

## INSTITUTIONAL CONTROL CONTRACT

\_\_\_\_\_ has entered into a Letter of Agreement pursuant to the [specific authority for cleanup Program, citing statute], with the Missouri Department of Natural Resources (the department) for (name of facility or site), a site of environmental contamination located at (address of facility or site) in the city (town, village) of \_\_\_\_\_, \_\_\_\_\_ County, Missouri.

The site or facility (hereafter "site") has been remediated to a level safe for its current or intended use as specified in the department-approved remedial action plan provided that certain risk reduction and exposure control measures remain in place. The department has an obligation to protect human health and the environment and to assure that all of the risk reduction and exposure control measures in the remedial action plan (and any amendments thereto) remain intact, functional, and able to serve their intended purposes.

**NOW THEREFORE**, [insert name of Property owner], [insert mailing address of owner], (hereafter referred to as the "Owner") hereby agrees that:

1. The Owner shall pay to the department a one-time fee of \$ \_\_\_\_\_ to be used to fund regular inspections of the risk reduction and exposure control measures implemented at the site for as long as necessary.
2. The Owner agrees to execute and file with the \_\_\_\_\_ County Recorder of Deeds a Restrictive Covenant and Grant of Access pertaining to management of the contamination.
3. The Owner shall file this Agreement and the Restrictive Covenant and Grant of Access with the \_\_\_\_\_ County Recorder of Deeds within five (5) days of execution of this Agreement and provide to the department evidence of such recording, to include a true copy of the documents as filed and stamped by the \_\_\_\_\_ County Recorder of Deeds.
4. A copy of the Letter of Completion shall be filed by the Owner with the \_\_\_\_\_ County Recorder of Deeds in the chain of title for this property. If the department determines that the Owner has failed to comply with the terms of this Agreement or the Restrictive Covenant and Grant of Access or fails to comply with the terms of the Letter of Completion or fails to comply with the department-approved remedial action plan, the Letter of Completion as provided by the department pertaining to this site may be rescinded and deemed null and void at the discretion of the department. In this event, a notice shall be filed by the department with the \_\_\_\_\_ County Recorder of Deeds and attached to the Letter of Completion Letter.

The undersigned person executing this Agreement on behalf of the Owner represents and certifies that he or she is truly authorized and have been fully empowered to execute and deliver this Agreement.

**IN WITNESS WHEREOF**, the Owner of the site has caused this Agreement to be executed on this \_\_\_\_\_ day of \_\_\_\_\_, 20\_\_\_\_.  
Signed in the presence of Property Owner subscribed and acknowledged.

Signature of Owner  
Subscribed and acknowledged before me this \_\_\_\_ day of \_\_\_\_\_,  
20\_\_\_\_\_.

\_\_\_\_\_  
Notary Public  
My commission expires \_\_\_\_\_.

**IN WITNESS WHEREOF**, the Missouri Department of Natural Resources has caused this Agreement to be executed on this \_\_\_\_\_ day of \_\_\_\_\_, 20\_\_\_\_.

Signed in the presence of the Missouri Department of Natural Resources subscribed and acknowledged.

\_\_\_\_\_  
Director  
Hazardous Waste Program  
Missouri Department of Natural Resources

Subscribed and acknowledged before me this \_\_\_\_\_ day of \_\_\_\_\_, 20\_\_\_\_\_.

\_\_\_\_\_  
Notary Public

My commission expires \_\_\_\_\_.

## APPENDIX J-4 MODEL NOTIFICATION LETTER

Letter template for use by site owner/operator or remediation applicant to satisfy the requirements of the [rule]:

### NOTICE

*[Date]*

*[Address]*

Dear *[Adjacent Property Owner]* *[Unit of Local Government]*:

*[Name of person or entity performing remediation]* is performing an environmental response action at *name and physical address of site (not a P.O. Box)*. The response action is being performed because *[state the nature of the release]*. The response action consists of *[describe the nature of the response action]*.

To protect human health, public welfare and the environment Missouri regulations require that *[name of person or entity performing remediation]* either clean up the site, including groundwater contamination, or demonstrate that the groundwater in the area of the release will not be used as potable water. (“Groundwater” is the water beneath the ground stored in the pores of soil and rock; some communities and homeowners pump this water out of wells to supply potable water. “Potable” means fit for human consumption including drinking, bathing, inhalation of vapors, preparing food, washing dishes, and so forth.) The *[name of unit of local government, address]* has an ordinance prohibiting the use of groundwater for potable water. Under Missouri regulations, local ordinances that effectively prohibit the installation and use of new potable water supply wells may be used to establish groundwater remediation objectives ([rule]). The Missouri Department of Natural Resources (“the department”) has determined that the ordinance adopted by *[name of unit of local government]* meets the regulatory requirements. This ordinance has been used by the department in reviewing *[name of person or entity performing remediation]* request for groundwater remediation objectives as part of this response action.

Your property, *[legal description or reference to a plat showing boundaries]* , is included in the area affected by the ordinance. This means that you cannot install or use a private, potable water well on your property. Based on the remediation objectives established in reliance on this ordinance, groundwater beneath your property may not be suitable for human consumption. Missouri regulations require that you be notified of these facts. The ordinance may be found at *[citation to unit of local government’s municipal code]*. If you wish to obtain a copy of the ordinance, please contact *[unit of local government, address and phone number]*.

To learn more about *[name of site]*, please contact either *[name of contact person, address and phone number]*, or the Missouri Department of Natural Resources, Hazardous Waste Program project manager, *[assigned project manager, address and phone number]*. You may also obtain a copy of the complete department file on *[name of site]*. To do so, you will need to submit a written request with your signature to the [Custodian of Records], Missouri Department of Natural Resources, Hazardous Waste Program, P.O. Box 176, Jefferson City, MO 65102. When you request a copy of the file, please reference the file heading shown below:

*[Missouri Inventory Number/County*

*Site Name/City*

*Site Address*

*Agency Site Number]*

Sincerely,

*[Name of person or entity performing remediation]*

## APPENDIX K

### DATA QUALITY MANAGEMENT PLAN

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As discussed in Section 6.2, the department operates under its Quality Management Plan when collecting or overseeing the collection of environmental sampling data. This plan requires that:

Each ALPD, GSRAD or WPSCD program which generates environmental data will develop a Quality Assurance Project Plan (QAPP) following the current version of Requirements for Quality Assurance Project Plans (EPA QA/R-5) and will ensure that adequate resources (both monetary and staff) are provided to support the QA effort, and will be responsible for implementation of the QAPP. It will be the responsibility of the ALPD, GSRAD or WPSCD program to ensure that QAPPs or other appropriate quality management tools are developed by any subgrantees, contractors, or, in some cases, the regulated community, who generate environmental data. For examples, sites undergoing corrective action under RCRA are typically required to have QAPPs... (pp. 3-4).

And:

...the Quality Management Plan (QMP) for Missouri...covers all intramural and extramural monitoring and measurement activities that generate and process environmental data for use by the MDNR-ALPD/GSRAD/WPSCD. (p. 2).

A copy of the Quality Management Plan is available from the department or from the department's web site. EPA QA/R-5 contains further guidance on the details required to ensure data quality in field measurements.

#### **Minimum Subject Areas**

In order to meet the requirements of the department's Quality Management Plan, this appendix outlines the minimum subject areas that need to be addressed to meet quality assurance/quality control requirements for environmental measurement data that is collected as part of the MRBCA process. These minimum requirements include the necessary components for Work Plans submitted for department approval to conduct environment data collection and the necessary QA/QC documentation to be submitted after data collection.

- I. Work Plans for Site Characterization
  - A. Sampling and Analysis Plan
  - B. Field Sampling Plan
  - C. Quality Assurance Project Plan
  - D. Health and Safety Plan
  
- II Characterization Reports including Tier 1, Tier 2 and Tier 3 Risk Assessment Reports



- A. Field QA/QC documentation requirements
- B. Laboratory QA/QC documentation requirements

### III Risk Management Plan

If the Risk Management Plan involves environmental data collection such as further site characterization, confirmatory samples following remedial activities or monitoring then:

- A. Sampling and Analysis Plan
- B. Field Sampling Plan
- C. Quality Assurance Project Plan
- D. Documentation of the Health and Safety Plan

If the Risk Management Plan does not involve sampling but only LTS and AUL etc. then data QA/QC would not be a component.

### IV Completion of Risk Management Plan

This is covered in Section 12 but if the Risk Management Plan involves sampling then:

- A. Field QA/QC documentation requirements
- B. Laboratory QA/QC documentation requirements

## **QA/QC Documentation Requirements**

With respect to II – A. above, the following details must be considered in field QA/QC planning and documentation:

- Calibration and maintenance records for field instrumentation,
- Documentation of sample collection procedures,
- Reporting of any variances made in the field to sampling plans, SOPs or other applicable guidance documents,
- Reporting of all field analysis results,
- Documentation of sample custody (provide copies of Chain-of-Custody documents),
- Documentation of sample preservation, handling and transportation procedures,
- Documentation of field decontamination procedures (and if applicable, collection and analysis of equipment rinsate blanks),
- Collection and analysis of all required duplicate, replicate, background and trip blank samples, and
- Documentation of disposal of investigation-derived wastes.

With respect to II – B. above, laboratory analytical data must be accompanied by QA/QC sample results. The following details must be considered in laboratory QA/QC planning and documentation:

- If the published analytical method used specifies QA/QC requirements within the method, those requirements must be met and the QA/QC data reported with the sample results.

- At a minimum, QA/QC samples must consist of the following items (where applicable):
  - Method/instrument blank,
  - Extraction/digestion blank,
  - Initial calibration information,
  - Initial calibration verification,
  - Continuing calibration verification,
  - Laboratory fortified blanks/laboratory control samples,
  - Duplicates, and
  - Matrix spikes/matrix spike duplicates,
- Documentation of appropriate instrument performance data such as internal standard and surrogate recovery.

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## APPENDIX L DEFINITIONS

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**7Q10:** the average minimum flow of a stream for seven consecutive days that has a probable recurrence interval of once-in-ten years.

**Activity and Use Limitations (AULs):** mechanisms or controls that ensure that ~~pathways of~~ exposure pathways to COCs, through current or reasonable future uses, are not completed for as long as the COCs pose an unacceptable risk to human health, public welfare or the environment.

**Acute water quality criterion for the protection of aquatic life:** the highest concentration of a pollutant to which aquatic life can be exposed for a short period of time (1 hour) without harmful effects. Acute criteria apply to unclassified waters and to classified waters at the edge of the zone of initial dilution.

**Additivity of risk:** sum of risk for each chemical and each route of exposure.

**Chronic water quality criterion for the protection of aquatic life:** the highest concentration of a pollutant to which aquatic life can be exposed for an extended period of time (4 days) without harmful effects. Chronic criteria apply to classified waters only at the edge of the mixing zone.

**Cumulative site-wide risk:** sum of risk for all chemicals and all ~~routes of~~ exposure exposure pathways.

**Domestic consumption:** ingestion and inhalation of vapors generated by indoor water use activities such as showering and washing.

**Exposure domain:** area that contributes chemicals that result in exposure to a particular receptor by a specified route of exposure.

**Exposure ~~P~~pathway:** The course a chemical takes from a source to the receptor. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of intermedia transfer) also is included. The exposure pathway is considered complete if there are no discontinuities in or impediments to movement from the source of the contaminant to the receptor.

**Habitat:** a place where an ecological receptor such as an animal or plant normally lives.

**Hydraulic conductivity:** ~~the~~ the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

**Hyporheic zone:** Region beneath and adjacent to streams and rivers where surface and groundwater mix.

**Long-term stewardship:** an appropriate system of controls, institutions and information necessary to fully protect human health, public welfare and the environment into perpetuity.

**Mixing zone:** an area of dilution of effluent in the receiving water beyond which chronic toxicity criteria must be met [10 CSR 20-7.031(1)(N)].

**Off-site:** Areas beyond the site that potentially become contaminated.

**Practical Quantitation Limit:** Lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions.

**Receptor:** An organism that receives, may receive, or has received exposure to a COC as a result of a release. Under the MRBCA program, human receptor refers to a resident child, resident adult, non-resident adult, or construction worker.

**Remediating party:** all private entities and their designees, collectively and generically, ~~involved with the site~~, such as responsible parties, development interests, landowners and others directly involved in the ~~evaluation and management~~remediation of a particular contaminated site.

**Sensitivity analysis:** Evaluation of the calculated risk or target levels for different alternatives of possible input parameters.

**Site:** areal extent of contamination.

**Surficial soil:** from 0-3 feet below ground surface (bgs).

**Subsurface soil:** from 3 feet bgs to the water table or, if the groundwater is shallow, less than 15 feet bgs below the water table.

**Tentatively Identified Compound (TIC):** a compound in the chromatogram of a mass spectrometry method identified solely by computer comparison to a mass spectral reference library. The identity of the compound is not based on a comparison to any compounds for which the method has been calibrated.

**Unrestricted use levels:** chemical concentrations at which soil and groundwater at a site are safe for residential land use and domestic use of groundwater.

## APPENDIX M

### SITE-SPECIFIC BACKGROUND CONCENTRATIONS

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#### INTRODUCTION

“Background” can be defined as concentrations of chemicals in soils or groundwater in the immediate area of a contaminated site. Background concentrations can be naturally occurring (the concentration is not due to a release of chemicals from human activities), or anthropogenic (the presence of a chemical in the environment is due to human activities, but not the result of site-specific use, waste or product release, or industrial activity).

Naturally occurring metals and other chemicals are found in natural soils and groundwater at varying concentrations, depending upon the topography, geology, geography and physical, biological, and chemical properties of the soil and groundwater. The source of these chemicals is typically from geomorphological processes, such as erosion, weathering, and dissolution of mineral deposits.

Anthropogenic impacts include lead from automobile emissions, arsenic from use of defoliants, pesticides in agricultural areas, and poly-nuclear aromatic hydrocarbons resulting from combustion of hydrocarbons. For anthropogenic impacts, the chemicals usually result from the use of a product in its intended manner and may be present at low levels over large areas.

In addition to natural and anthropogenic sources, chemical concentrations in soil and groundwater may be the result of on-site activities at contaminated sites. The assessment screening strategy and remediation strategy for cleanup of such sites, as well as implementation of institutional controls, requires that background concentrations of chemicals be determined in order to ascertain the extent to which the contamination can be attributed to on-site activities.

The determination of “background” contains two fundamental challenges. First, “background” inherently implies natural variability, thus creating a distribution or a range that varies with the spatial distribution of the samples. Defining a site-specific background concentration level for background concentrations is therefore difficult. Second, soil and groundwater are heterogeneous in nature. The need to replicate the “background” as closely to the site characteristics as possible, minus the on-site activity, poses a number of challenges related to the selection of the background site as well as the sampling plan.

Determination of background concentrations for the chemicals detected at a site is very important for establishing the site-specific chemicals of concern (COC) for which cleanup levels must be determined. Because chemicals not related to the past or current site-related activities may be present at a site, it is important to determine the background concentrations for those specific chemicals. Further, for site-related chemicals, if the background concentrations are greater than the target cleanup levels, a decision must be

made as to whether the site should be cleaned up to background levels or to risk-based levels. It may not be feasible or practical to clean up the site to target cleanup levels due to cost-effectiveness, technical impracticability, and the potential for recontamination of remediated areas from surrounding areas with elevated background concentrations.

## **METHODOLOGY**

Prior to determining the site-specific background concentration for any chemical, the following approach should be used to determine if background determination is necessary.

First, determine whether the chemicals detected on-site are due to the site or nearby activities. To eliminate chemicals not related to site activities, historical research and interviews should be performed to determine the past and current activities for the site and adjacent properties.

The department has established three levels of cleanup criteria:

- a. Default Target Levels,
- b. Tier 1 Risk-Based Target Levels, and
- c. Site-Specific Target Levels.

For soil and groundwater, determination of background concentrations is necessary for chemicals that exceed both Default Target Levels and appropriate Tier 1 risk-based target levels.

For some chemicals, the only applicable pathway may be soil to groundwater. If so, the Synthetic Precipitation Leaching Procedure (SPLP) may be used to determine if the chemical concentration in the soil has the potential to leach from the soil and migrate into the groundwater and cause groundwater impacts at levels above the approved groundwater target level for that chemical. The SPLP analysis should be performed on a number of soil samples with the highest levels of impact for the specific COC and the results compared to the target groundwater levels. The number of samples for SPLP analysis would be determined on a site-specific basis and approved by the department, considering the size of the impacted area, heterogeneity of the impacted soils, and other site conditions. If all SPLP results are below the target groundwater levels, then those specific chemicals do not need to be considered in determining the cleanup objectives for the site.

The background area should be on the site or in close proximity to the site. It must be shown that the area selected has not been impacted by historical or current site activities, nearby activities, or fill materials that share similar physical, chemical, biological, and geological characteristics with the site.

In the selection of a background area, the following points must be taken into consideration:

- a) **Background soil samples must be taken from similar soil characteristics.** Because of the heterogeneity of soils, it may be necessary to establish more than one background concentration for a COC. Soils are essentially heterogeneous, and their particle size, pH, salinity, cation exchange capacity, and soil organic carbon content vary spatially – both vertically and horizontally. It may be necessary to determine background concentrations for different stratigraphic intervals or for areas of impact that are widely separated by non-impacted areas.

Because of these considerations, it is important to ensure that factors that affect the concentration of chemicals in the soil are considered when collecting samples from the site and off-site. As much as possible, soil samples must be taken from identical soil depths, identical soil textures, identical pH values, and at the same time of the year as for the impacted soil horizons.

Grid sampling can be an effective way of obtaining representative background samples; however, care must be taken to avoid including samples from impacted areas, or samples from areas or intervals that have significantly dissimilar physical, chemical, and biological characteristics.

- b) **Background water samples must be taken from areas of similar groundwater characteristics.** To determine background concentrations for groundwater, sampling must be conducted for a minimum of one year in four consecutive quarters, unless a different schedule is approved by the department. The wells used in the background determination must be:
- Located in areas not affected by the release,
  - Screened in the same geologic unit that is contaminated on site,
  - Located up gradient from the release area(s),
  - Sufficient in number to account for all possible off-site releases, and
  - Sufficient in number to adequately characterize the hydrogeologic setting.
- c) **Location of the background area is important.** Background area must reflect the soil and groundwater characteristics at the site, and the background area must be in close proximity to the site, without having been impacted by site or nearby activities. Background concentrations of chemicals can vary significantly from metropolitan to non-metropolitan areas.
- d) **Evaluation of land use and prior history is important.** Information of prior land use at and near the site should be collected to determine if prior human activities contributed to background concentrations and to the presence of certain chemicals unrelated to activities at the site or from nearby sites. Similarly, if the site contains fill materials, it is important to recognize the potential for contaminants because of the fill materials, rather than because of site or nearby activities.
- e) **An appropriate number of samples must be taken.** Sample collection must take an appropriate number of samples for the statistical method being used and



considering site-specific conditions. The sampling strategy should be designed to obtain background levels that are truly representative of the site. Care should be taken if composite sampling will be used to reduce the total number of samples, such that the composites should represent background conditions and not create biased results. The number of samples to be obtained must be supported by a valid sampling strategy approved by the department.

Any statistically valid approach approved by the department can be used to develop site-specific background values. The approach must be appropriate for the characteristics of the data set being evaluated.

## **APPROVAL**

The basis for approval of a site-specific background concentration for a specific chemical is determined by a review of the following criteria:

- a) Evaluation of all samples used in the background data set to determine if appropriately representative of site conditions based on locations, depths, number of samples, sampling methods, and laboratory analysis methods.
- b) Evaluation from a toxicological and risk-assessment standpoint to determine if the background levels are inherently too high for a potential exposure from the intended future land use.
- c) Verification of statistical methodology, assumptions used and results obtained.

## **APPLICATION**

An approved background concentration of a chemical may be used on a site-specific basis for the assessment screening strategy, or as the cleanup level under all three standards (Default Target Levels, Tier 1 risk-based target levels, and site-specific target levels). In some cases, the site-specific background concentrations may be higher than the health-based cleanup level. For example, the health-based concentration of a chemical in soil may be lower than the naturally occurring concentration of that chemical in a certain soil type or location. Therefore, it would not be practical to clean up to the health-based level.

If the site-specific background concentration for a specific chemical is higher than the levels detected in all the samples obtained and analyzed from the site, then that chemical can be dropped from consideration in the site cleanup goals.

## APPENDIX N

### CLEANUP LEVELS FOR SURFACES AND BUILDING INTERIORS

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#### ASBESTOS ABATEMENT

Clearance criteria for asbestos abatement projects that occur within the confines of a building are specified at 10 CSR 10-6.240(H). The department must approve any deviations from these clearance criteria.

#### LEAD ABATEMENT

For lead abatement projects that occur within the confines of a building the clearance criteria for dust wipe samples are as follows;

##### Residential

- ~~50-40~~ micrograms of lead per square foot for uncarpeted floors
- 250 micrograms of lead per square foot for windowsills
- 800 micrograms of lead per square foot for window wells

##### Non-Residential

- 200 micrograms of lead per square foot for floors
- 500 micrograms of lead per square foot for windowsills
- 800 micrograms of lead per square foot for window wells

The department must approve any deviations from these clearance criteria.

Note: The Residential clearance criteria are derived from 40 CFR 745.65(b), as proposed in the June 3, 1998 *Federal Register*. The Non-Residential clearance criteria are derived from the Missouri Office of Administration's Lead Abatement Specifications.

#### PCB-CONTAMINATED STRUCTURES

For PCB-contaminated concrete, the cleanup criteria shall be 10 ppm for destructive core sampling and 10  $\mu\text{g}/100\text{ cm}^2$  for surface wipe sampling. Because concrete is permeable, destructive core sampling or its equivalent is required for PCB-contaminated concrete. The wipe sampling may be optional. The department may consider higher cleanup criteria for PCB-contaminated concrete if the concrete is effectively encapsulated with an impermeable surface coating. In this case, a restrictive covenant would be required to ensure long-term maintenance of the surface coating.

For PCB contamination on impervious solid surfaces, such as a metal wall, the cleanup criteria shall be 10  $\mu\text{g}/100\text{ cm}^2$  for a surface wipe sample.

Note: The 10  $\mu\text{g}/100\text{ cm}^2$  criteria are derived from the USEPA's PCB Spill Cleanup Policy, 40 CFR 761, Subpart G. The USEPA's Spill Cleanup Policy does not prescribe destructive core sampling for PCB-contaminated concrete. Wipe sampling alone is not

sufficient to verify cleanup of PCB-contaminated concrete. It is possible to remove PCBs from the surface of the concrete through solvent washing and leave behind significant PCB contamination deeper in the concrete. With time, PCBs may again migrate to the surface, creating a potential exposure. This scenario illustrates the need for destructive core sampling.